THE UNIVERSITY OF ALBERTA

A GEOLOGIC, ECONOMIC AND ISOTOPIC EVALUATION OF CRAIGMONT MINES, BRITISH COLUMBIA

BY

© LAWRENCE [illegible] [illegible]MAS, B.Sc

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Geologic, Economic and Isotopic Evaluation of Craigmont Mines, British Columbia," submitted by Lawrence P. Chrismas, B. Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Craigmont's history, which is summarized from discovery to production, shows the evolution of a small mineral prospect to a producing mine. Geophysical and geochemical exploration techniques provided the base for diamond drilling that exposed the economic mineralization.

Craigmont orebodies are located in a steeply dipping, drag-folded section of carbonate and skarn rocks within the contact aureole at the southern end of the Guichon Creek Batholith. The host rocks belong to the Nicola Group of Late Triassic age. On the basis of geology, Craigmont orebodies formed between Late Triassic (Karnian) and Early Cretaceous (Albian) and possibly by Middle Jurassic time. Rubidium-strontium age dating of the potassium feldspar gangue, contemporaneous with a late phase of mineralization, together with Guichon Batholith whole rock samples, gave an isochron indicating an age of 198 $\pm$ 0.4 million years. This implies nearly contemporaneous origin for the Guichon Batholith, Bethlehem porphyry deposit, and the Craigmont contact metamorphic deposit.

The only ore mineral is chalcopyrite, commonly associated with varying amounts of magnetite and specularite. These minerals were formed in two phases: (1) during initial skarn formation, and (2) during a slightly later veining phase. Sulfur isotopic data suggests that during the initial skarn formation a combination of country rock sulfur

(sulfurization) and magmatic sulfur were concentrated in the orebodies. During the second phase, the sulfur was derived mainly from a deep-seated source, probably as a late-stage differentiate of the cooling batholith. K-feldspar gangue associated with the second phase of mineralization has an initial Sr^{87}/Sr^{86} ratio of 0.704, similar to recent oceanic basalts. The analyzed sulfide minerals associated with these veins have δS^{34} values near the zero permil reference value representing meteoritic sulfur. Oxygen-carbon isotope measurements of carbonate skarn, and calcite interstitial to ore minerals, also support the above interpretations.

Craigmont's remaining life and future profits hinge on the price of copper and the cost of the sub-level cave mining method recently adopted following completion of the open pit. The present value of future profits appears adequately reflected in the common stock market price.

ACKNOWLEDGEMENTS

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Permission for this study from Craigmont Mines and special assistance from J. F. Bristow, senior geologist who supplied specimens, maps and information, is especially appreciated.

The writer is also grateful to Dr. W.V. Smitheringale who offered helpful comments on parts of the manuscript. My wife deserves thanks for her help and cooperation.

Appreciation is also expressed to the University of Alberta for financial assistance in graduate teaching and service assistantships and an intersession bursary. The isotope work was carried out within the University of Alberta isotope geology program which is supported by a National Research Council grant. The Department of Physics maintained the mass spectrometers used in this project.

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CHAPTER I

INTRODUCTION

In recent years the study of economic geology has lost status compared to other specialized fields of geology. However the study of mineral deposits is still vital, though such studies rarely include the broad economic appraisals that were important to early economic geologists. Flawn (1956) emphatically asks, "Who took the 'economic' out of economic geology?" He holds that problems of mineral deposits and mineral resources are the responsibility of the geologist and should not be left to the engineer or the economist.

Scope of the Study

In an attempt to utilize the principles of economic geology, this thesis on Craigmont Mines, third largest copper producer in British Columbia, considers both geologic and economic factors of the mineral deposit. A historical documentation of the Craigmont Mine from discovery to production and a resumé of the mining and milling methods are included. The preproduction costs and economic factors affecting the exploitation of copper are also considered. An attempt is made to relate the local mine geology to the regional setting, and in addition, certain aspects of petrology and mineralogy from the mine area are described in detail.

Also included in the thesis are the economic implications of a

reconnaissance geochronological and isotope study. Radiometric dating on six samples was used to determine the age of mineralization in relation to age of the Guichon Creek Batholith. A Bernard-Price Institute rubidium-strontium isochron plot was used to date six whole rock samples, mostly from the mineralized area at Craigmont. Results are discussed in relation to the widespread Mesozoic plutonism and metallogeny of the western Cordillera.

Thirteen samples were analyzed for their sulfur isotope ratios, using chalcopyrite as the major sulfur-bearing mineral. A comparison was made with a few pyrite samples taken from the Guichon Batholith at some distance from the orezone. Results from this reconnaissance investigation are discussed in respect to the behaviour of sulfur isotopes, genesis and history of Craigmont mineralization.

Twenty-eight carbonate samples were analyzed for their carbon and oxygen isotopes. Many of the samples selected were from the ore bearing skarn zone while the others were collected away from known mineralization. Results of this investigation are compared with the isotope ratios of other hydrothermal carbonates and collated with conclusions of the sulfur study.

Craigmont was selected for investigation because of its interesting early history, strategic location in the central copper belt of British Columbia, and proximity to the Guichon Creek Batholith. Craigmont, which is approximately seven years old, began as an open pit mine. An interesting economic sidelight of the major study is the current transition

from open pit to underground mining.

Craigmont was visited in late June 1967 to collect laboratory specimens, obtain a general picture of the geology, and observe mining and milling operations. The history, past and present mining methods, and economics have largely been synthesized from published literature. The mine geology has been obtained in part from mine maps and sections and through personal communication with J. F. Bristow, senior Craigmont geologist, as well as from various publications. Sample locations, analytical techniques, and sample preparation methods used for the isotope investigations are described in the appendices.

<u>Geography</u>. The Craigmont Mine is situated in the southern part of the Highland Valley Mining District, (latitude 50° 12' 28" N, and longitude 120° 43' 48" W), 240 miles northeast of Vancouver and 400 miles southwest of Edmonton. The mine buildings and open pit are located ten miles northwest of the town of Merritt which has a population of 4500 (1966 Census of Canada). Other major towns with their populations and distances from Craigmont are Kamloops, 10, 759, 40 miles northeast, and Princeton 2163, 60 miles south. Two other small towns to the northwest are Spences Bridge and Ashcroft. These are located on Figure 1.

Craigmont's 30 million ton ore body is located about midway in a NW-SE trending belt of copper mineralization. Some 15 miles to the northwest are two interesting properties: the Highmont Mining

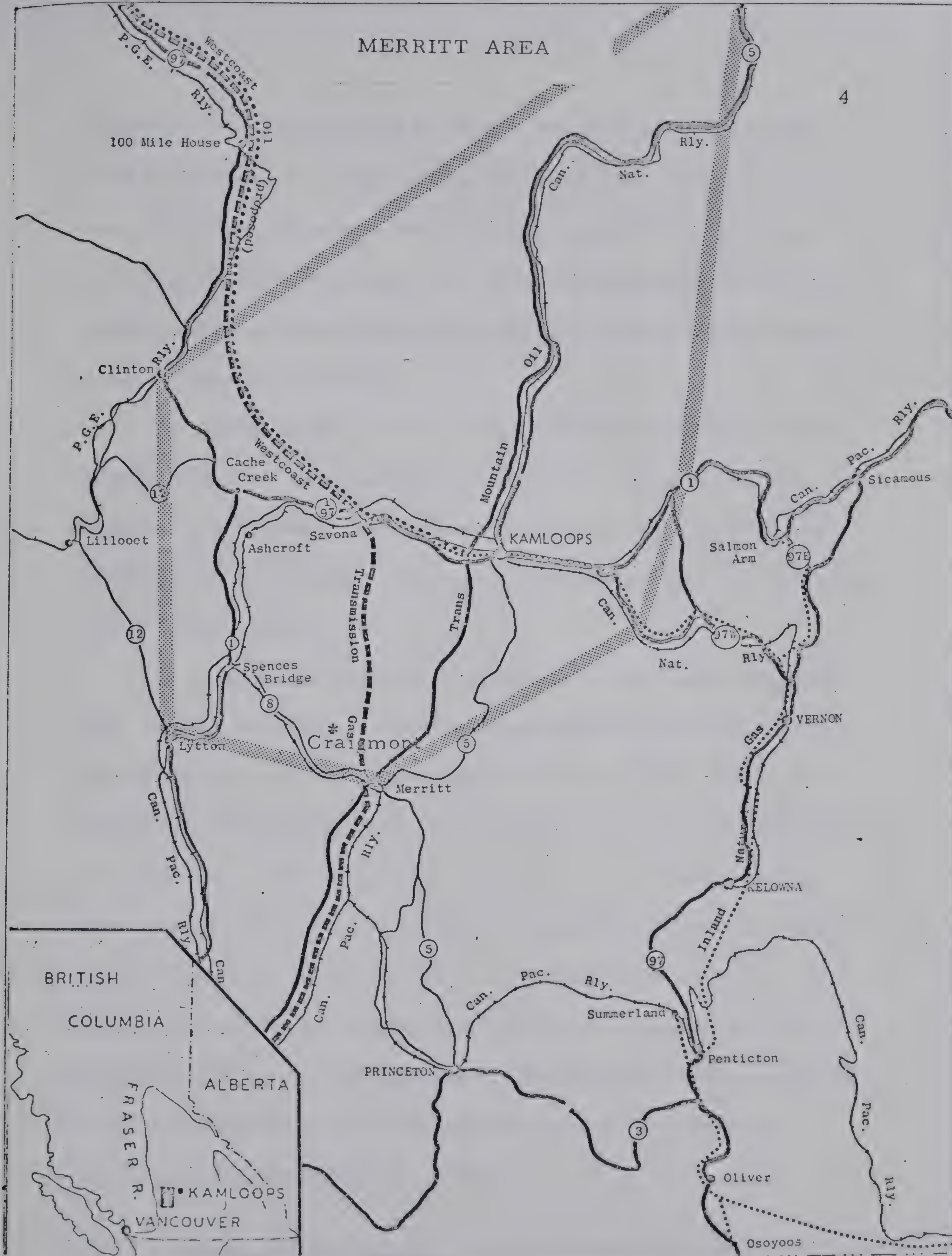


Figure 1. Index map showing location of Craigmont Mines.

Corporation with an estimated 45 million tons grading 0.30% copper; 0.09% molybdenum to a depth of 250 feet; and Lornex Mining Corporation, west of Highmont with some 330 million tons of ore grading 0.44% copper; 0.031% molybdenum. Both companies are carrying on underground development with bulk sampling and metallurgical testing to support feasibility studies.

Bethlehem Copper, some 5 miles northwest of Lornex, started production in 1963, two years after Craigmont. Ore reserves are estimated at 100 million tons, presently indicated, grading 0.6% copper with some molybdenum. Operated as an open pit mine it is currently milling 12,000 tons per day.

About 60 miles southeast of Craigmont is the Copper Mountain Mine. Dating from 1925, intermittant production from this property aggregated about 4 million tons of copper ore up to 1930. During its latest production period, 1937-1957 some 35 million tons of copper ore were produced. After a period of nine years this dormant property again became of interest and currently is being reassessed, in conjunction with adjoining claims, by Newmount Mining Corporation. On the Ingerbelle property adjacent to Copper Mountain, Newmont has outlined an estimated 40 million tons grading 0.7% copper and recent drilling on the Copper Mountain property has indicated comparable tonnages (Northern Miner, December 21, 1967).

Physiography and climate. Craigmont Mines lies within the Thompson

Plateau physiographic division of the Interior Physiographic Province. The Thompson Plateau is a gently rolling upland with the exception of some resistant masses of rock which rise to 6000 feet. Craigmont is situated on the eastern slope of Promontory Hill which at 5600 feet is the highest in the area. Promontory Hill is bounded to the south by the Nicola River Valley and to the east by the Guichon Creek Valley. Just west of Merritt, Guichon Creek joins the Nicola River which flows west to the Fraser River. Many surficial features are the result of Pleistocene glaciation that advanced from the northwest. Till and colluvium cover much of the area. Drumlinoid ridges and meltwater channels illustrated on the surficial geology map of the area by Fulton (1962) are striking evidence of glaciation. As a result of till cover, outcrops are scarce. Fulton's map indicates only about 20 percent of the bedrock is exposed and even this occurs for the most part as talus slopes or in recent road cuts. Contributing to the lack of outcrop is the semiarid climate. The annual precipitation of 14 inches occurs mainly as snowfall during the winter months, resulting in many small intermittant streams. Vegetation consists of thick groves of Lodgepole pines and small Douglas-fir and Engelmann-spruce on the hills with sage brush and grasses in the valleys.

Accessibility. Hard-surfaced highways, railroads, electric power lines, oil and gas transmission lines, within short distances are favourable factors in the low cost operation of Craigmont Mines.

Craigmont is now connected by a four mile hard top road built with assistance of the British Columbia Department of Mines to the Merritt-Spences Bridge Highway and the railway at a point six miles west of Merritt. The building of this road is evidence of the government's progressive attitude toward the mining industry. Other major hard-surfaced highways serving Merritt and the mine are Princeton-Merritt from the south; the Spence's Bridge Highway from the northwest; and the Kamloops-Merritt road from the northeast.

The Kettle Valley branch line of the Canadian Pacific Railroad also runs through Merritt providing economical transportation for bulk goods. The closest commercial air terminal is located at Kamloops. Merritt has a short runway for small aircraft.

A British Columbia Hydro's electric transmission line also passes through the area along with oil and gas pipelines of Trans-Mountain Oil Pipelines and Westcoast Transmission Company giving cheap and convenient energy supplies.

Review of previous work. In 1897, and possibly as early as 1877, prospectors were in the Craigmont area searching for copper. The early British Columbia Minister of Mine's Annual Reports describe the early attempts of the copper prospectors and their findings of minor occurrences of copper in the Merritt area. The first detailed report on the geology and mineral deposits was prepared by Cockfield (1948), a Geological Survey of Canada geologist. Four years later Duffell and

McTaggart (1952) published a memoir on the geology of the Ashcroft area which is due west of Cockfield's Nicola map-area. These two memoirs, 249 and 262, are basic references. The next work done in the area was detailed mapping by Carr of the British Columbia Department of Mines, assisted by staff from Craigmont. Their results are presented in a report and small map extending south and west from the Craigmont mine (Carr, 1960).

Many companies are still actively exploring in the Craigmont area and because of this detailed information on geology and structure of the mine has not been available for publication. Rennie et al., (1961) and Carr (1966) presented generalized reports of the geology and structure of the mine. Two recent doctoral theses (Keevil, 1965; Drummond, 1966) present more detailed aspects of the history, geology, and exploration techniques at Craigmont.

The Guichon Creek Batholith that occurs just north of Craigmont and is host rock for the Bethlehem and Lornex deposits has been the subject of two papers by White et al., (1956 and 1967). Northcote (1968) has presented the most comprehensive study in his doctoral thesis on the "Geology and geochronology of Guichon Batholith, British Columbia."

CHAPTER II

GENERAL HISTORY OF CRAIGMONT

Introduction

Prospectors were in the Merritt area sixty years before Craigmont's discovery. In evidence is the Aberdeen copper mine, which was discovered in 1897 and located six miles northeast of what is now Craigmont (Cockfield, 1948). Early prospectors reported numerous occurrences of porphyry copper in the Guichon Batholith including the Eric showing, one and a half miles north of Craigmont. The early prospectors were apparently aware of the tendency for ore deposits to cluster near the borders of granitic intrusives so they used this as a prospecting guide. However, no pyrometasomatic deposits were reported until Calder's party discovered copper on the Paystin claims in 1953. Discovery of this small mineral prospect eventually led to the producing Craigmont mine.

Preliminary Exploration

Formed in 1946 in British Columbia, the Pinecrest Company, which became Craigmont Mines in 1951, had only meager finances. Most of its initial funds were used to prospect in the Princeton area. In 1954, Craigmont purchased 14 claims in the Merritt area from Ken Calder and associates. Test pits dug by Calder showed enough mineralization to interest Craigmont directors. These claims, the Paystin Nos. 1-6 and the Merchant Nos. 1-8 still form the core of the present mining operations.

Craigmont began its preliminary program by staking land adjacent to the purchased claims. The directors at the same time hired a consulting geologist and consulting engineer to sample the exposed mineralization and evaluate the property's potential. Although mineralization was exposed in only three trenches, the consultants reported encouraging possibilities for the property. Trench surface samples taken by the consultants averaged 0.80% copper (Craigmont First Annual Report, 1956). One of the consultant's prediction that the copper values would increase with depth influenced further work on the property.

A resident geologist was hired in April 1956 to direct prospecting, claim surveying, and trenching adjacent to the original trenches. Trenching with heavy duty earth-moving machinery helped uncover suspected mineralization, bedrock and structure in the outcrop-poor Merritt area. New mineralization was uncovered both by systematic trenching and accidentally while building a road to the Paystin prospect. Two mineralized zones on the property were located late that year. One was the Paystin zone showing mainly copper carbonates over a length of 600 feet and a width of 125 feet. The second zone on the McLeod claims was exposed 150 feet in a bulldozer trench (Craigmont information brochure, September 1956). Although the property had obvious potential several factors hindered work advancement. Outlined by Renshaw and Price (1958), the problems that existed were: (1) a large number of claims had few outcrops on them; (2) existence of apparently unrelated occurrences of copper; and (3) pressure from the directorate to begin diamond drilling.

To guide diamond drilling and provide possible solutions to geological problems, a geochemical soil survey and a magnetometer survey were carried out.

Geochemical and Geophysical Prospecting

A geochemical prospecting method used initially at Craigmont was the rubianic test for cold extractable copper which provided a rapid means of determining positive or negative results. The survey outlined four anomalous areas which were in part duplicated by the follow-up magnetometer surveys, but not by follow-up geochemistry (Rennie, 1961). Figure 2 showing the outline of the orebody at the 3700 foot elevation and the margin of the geochemical anomaly, indicates success of the method.

Results from the initial magnetometer survey are plotted along with the geochemical anomaly in Figure 2. The magnetometer survey was run on a 100 foot by 300 foot grid system. The anomalous readings produced by the orebody ranged from 5000 to 12,000 gammas over a 4000 gammas background indicating an area approximately 1000 feet long and several hundred feet wide. As shown in Figure 2, the anomaly is stronger at the eastern end because magnetite is present in large amounts and the orebody rakes close to surface. The anomaly is weaker to the west where the copper is associated almost solely with nonmagnetic specular hematite.

Two years after the initial geochemical survey another soil sampling survey was conducted but the original anomaly was not found. Warren

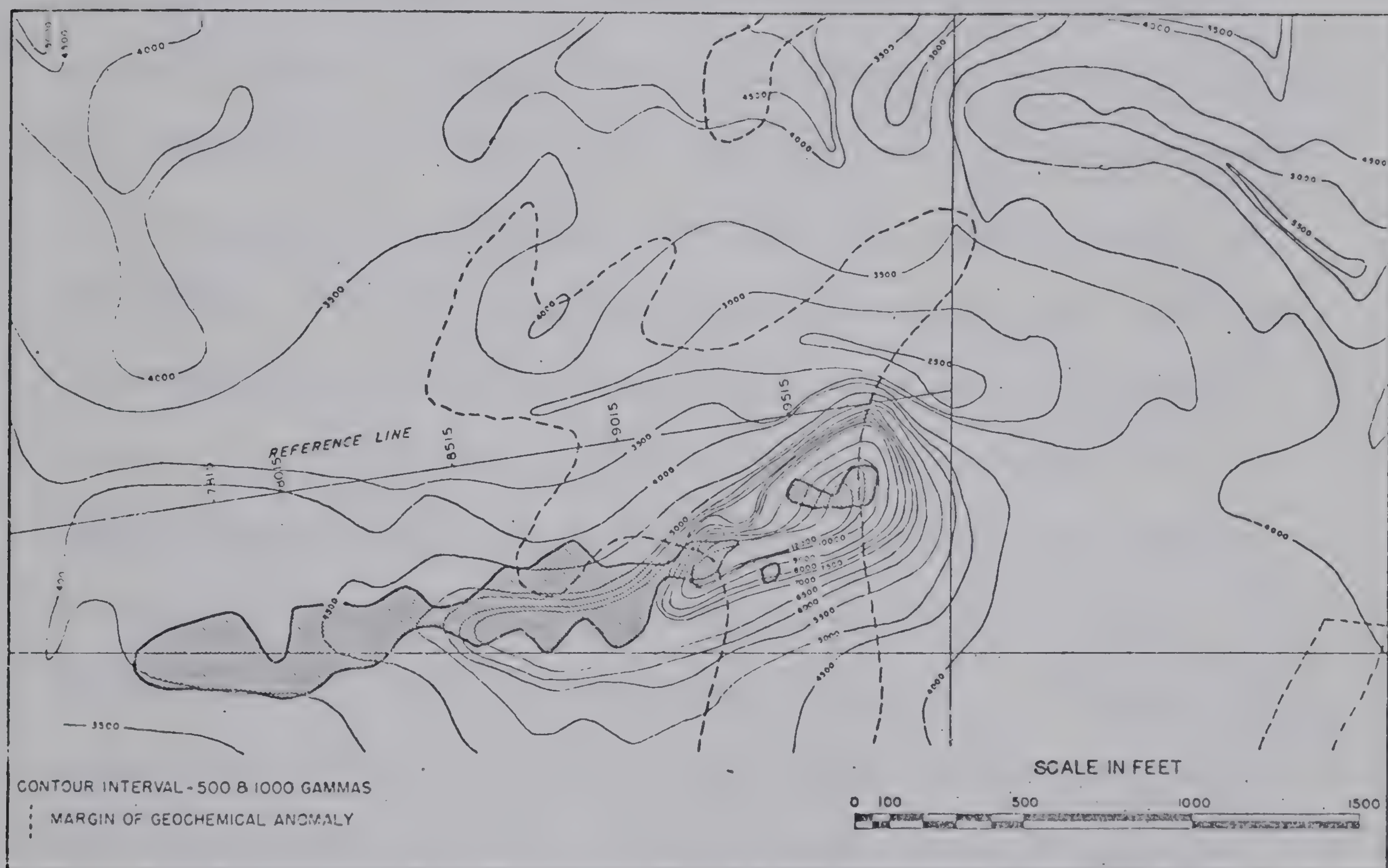


Figure 2. Plan showing the results of the initial ground magnetometer and geochemical surveys. The hatched area represents the horizontal projection of the ore outline at 3,700 feet elevation (from Chapman, 1962).

(personal communication) believes that soil sampling anomalies are influenced by the long dry and occasional wet spells that occur in this area. Following the unsuccessful second soil survey, Craigmont became the test site for a variety of geochemical methods. Keevil (1965) reports that most of the results were inconclusive with the exception of stream sediment sampling. Apparently the copper dispersion pattern is restricted due to the abundance of carbonate rocks in the area. Unfavourable results were obtained for trace analysis of molybdenum, calcium, manganese, magnesium, silver and zinc from core samples of the northern wallrock. No evidence of a mercury halo was detected in the soils near the ore-bodies possibly due to the overlying Kingsvale volcanic rocks. The vertical sampling of pit walls indicated that the erratic nature of the anomalies was due to the surface leaching of copper and carbonate. Two biogeochemical surveys by Newmont Mining Company in 1959 and Warren of University of British Columbia in 1962 conducted after mining began, were inconclusive. Warren felt that dust from the open pit mining on the vegetation influenced his survey.

Just as it had been a proving ground for geochemical methods, Craigmont became a test site for geophysical methods. Rennie (1961), Faessler (1962), Chapman (1962), and Keevil (1965), discussed the applicability of the various geophysical methods. Table I summarizes their results.

TABLE 1

SUMMARY OF THE GEOPHYSICAL PROSPECTING METHODS TESTED FOR THE CRAIGMONT TYPE MINERALIZATION

GEOPHYSICAL METHOD	SUCCESS OF METHOD	COMMENTS
Magnetic airborne	successful	A strong anomaly of approximately 500 gammas over the mineral deposit. The primary geophysical exploration technique.
Magnetic surface	successful	A strong anomaly from 7,000 to 14,000 gammas above background over the mineral deposit. Good indicator of rock types covered by overburden in the area.
Induced Polarization surface	successful	Good response received on traverses made over sulfides. The best of the electrical methods.
Seismograph*	successful	As used to determine thickness of overburden to aid in diamond drill location.
Magnetic underground	potentially successful	The close proximity of magnetite mineralization and mining equipment in the drifts produces a high noise level.
Magnetic drill hole	potentially successful	High noise level may be practical if magnetite is not found in core samples.
Gravity surface	potentially successful	Practical for detecting near-surface skarn ore in Nicola rocks. Surveys over Kingsvale volcanics unreliable due to high noise level.
AFMAG	potentially successful	At Craigmont the ore and faults give anomalies of similar intensity.
Gravity	more testing required	Background difficult to determine for this method. Kingsvale volcanics produce high noise level.

TABLE 1 (continued)

GEOPHYSICAL METHOD	SUCCESS OF METHOD	COMMENTS
Induced Polarization drill hole	more testing required	This method is still not technically developed by researchers. Has considerable potential as exploration tool.
Electromagnetic surface	unsuccessful	Craigmont contains approximately 5% sulfides which is less than the minimum amount for pronounced detection by E-M.
Electromagnetic airborne	unsuccessful	Due to poor conductivity and paucity of sulfides.
Self-potential	unsuccessful	Tests made over the ore body indicate a maximum anomaly of 30 mv which could easily be missed during exploration traverses. Also affected by topography.
Resistivity	unsuccessful	Tests indicate that different rock types may be outlined from resistivity surveys.
Scintillometer	unsuccessful	A traverse over orebody and a study of some core samples showed no anomalous response.

* This method is not a prospecting method but an aid to other methods.

Discovery

Overlapping of geochemical and magnetometer anomalies was enough to satisfy Craigmont directors that drilling was warranted even though no outcrops were present in the anomalous area. Diamond drilling began at the end of March 1957. The first two drill holes did not intersect mineralization. Before beginning Hole #3, a detailed magnetometer survey using a 50 foot grid spacing was made over the area again. This survey outlined a stronger pattern than the previous anomaly. Hole #3 was drilled on the new "Merrell anomaly" and intersected 157 feet of mineralization averaging 0.96% copper. This mineralization was encountered about a mile southeast of the showings that originally attracted prospectors to the area. The success of Hole #3 encouraged company officials to order the drilling of three more holes during the summer. Low grade copper mineralization was encountered in each of these holes.

Preproduction Development

The preliminary examination period ended in September 1957 with intersection of 645 feet of 1.91% copper and 37% iron mineralization in Hole #7. The consultants also added to the excitement by estimating that the orebody contained approximately 14 million tons of 1.2% copper.

During this period a staking rush occurred in the Merritt area. Close to 30 companies, many of them formed "overnight" in an attempt to capitalize on Craigmont's good fortune, were active in the area. The town of Merritt experienced "mining fever" as it became exploration

headquarters for many companies. Nearly all available land around Craigmont was staked including most of the open ground along the southern periphery of the Guichon Batholith.

Geology of the ore deposit and drilling results began attracting interest of major mining companies. Needing more capital to develop the property, Craigmont directors made an agreement effective November 1957 with Canadian Exploration Co. This subsidiary of Placer Development was to manage further development of the property and supply technical personnel. As part of the agreement CANEX was to purchase, in increments, 500,000 shares of Craigmont stock at 50 cents each.

Under CANEX's direction the number of active surface diamond drills increased from two to four in early 1958. During this period Hole #15 was drilled and the vertical core assayed 4.35% copper over 660 feet. In May 1958 CANEX engineers presented an extensive report recommending underground exploration based on an interpretation of cumulative drill results. Meanwhile Craigmont's directors presented a report to the shareholders summarizing an operating agreement between Craigmont, Noranda Mines, Peerless Oil & Gas and CANEX. The agreement stipulated that the latter three companies would operate the project for 60% of the net income from future production. The agreement which assured Craigmont 40% of the net income also stated that the decision to go into production had to be reached within three years. The new operators were also obligated to finance the preliminary development. In having these companies operate the project, Craigmont gained capable management,

exploration experience, and favourable financial standing.

Underground work at Craigmont began in July 1958. Birkett Creek Mine Operators, owned 50% by CANEX and 25% each by Noranda and Peerless Oil, carried out this program. The work consisted of an exploratory drift along the orezone footwall at the 3500 elevation for an approximate length of 3000 feet. Six crosscuts, 300 feet long, were driven at 200 foot intervals into the orezone. This program provided: (1) a check on the accuracy of surface diamond drilling; (2) samples for comprehensive metallurgical testing; (3) cheaper exploration of lower parts of orezone by diamond drilling; (4) observation of mining methods; and (5) a main haulageway (height 8-$\frac{1}{2}$ feet, width 9 feet). By the end of the year the adit, which penetrated 325 feet of till before entering bedrock, was 1000 feet long. Underground work progressed so rapidly that one-half of the previously estimated 14 million tons copper had been confirmed by June 1959. According to the directors this assured that the property could be brought into production.

By late 1959, the company announced implementation of the second phase of underground work and drilling. Within about six months approximately 75,000 feet had been drilled, mostly from underground. Drilling was done primarily on 100 foot sections in order to estimate ore reserves. This systematic drilling from underground drill stubs on the 3000 foot level facilitated discovery of the lower or syncline orebody in May 1960. Following this discovery Craigmont let a contract to remove the overburden and waste rock from the open pit area. Kie Mine Co. (Kiewit subsidiary)

completed the program ahead of schedule in early March 1961 and removed more than 3.5 million cubic yards of waste. During this operation in 1960, 135 men were employed in addition to 45 drillers, engineers, geologists and laborers. Work also began on a new adit on the 2400 level, for the main haulageway for all ore mined by underground methods.

At this time preliminary laboratory tests indicated that the copper was easily recovered from the ore and that an economic iron concentrate might be produced by flotation. However, later feasibility tests indicated that iron recovery was not economical due to high transportation costs.

The metallurgical staff of CANEX in conjunction with the milling consultants completed plans for the Craigmont mill, and construction began in late 1960 at the 2400 level site. The mill was designed to process about 4 000 tons per day of ore and could be expanded to include iron recovery equipment if necessary. Construction of the concentrator was completed in August 1961 and then mill tune-up began.

The Honorable W. K. Kiernan, British Columbia Minister of Mines officially started mill operation on September 15, 1961. Soon Craigmont was the second largest producing copper mine in British Columbia and in 1962-63 it became the leading producer.

Craigmont's early history shows that considerable perseverence and determination were exerted to find an economic mineral deposit. The use of modern geophysical and geochemical techniques interpreted by experienced personnel formed the base for the diamond drilling that exposed the copper mineralization. A carefully planned program by competent

geologists and engineers quickly outlined the orebody and determined the plan best suited for extraction of the ore. The Craigmont mine is an example of a profitable enterprise as much the result of management and personnel as the abundance of copper mineralization.

CHAPTER III

REGIONAL AND MINE GEOLOGY

Regional Geology

Cache Creek Group. The oldest rocks in the Craigmont area, the Cache Creek Group, summarized in Table 2, occur about 30 miles east along the upper Nicola River and also 25 miles northwest of Craigmont near Spatsum. This variably metamorphosed group was first named by Dawson in 1879. The predominant rock is black argillite interbedded with minor quartzite, conglomerate and breccia. Contemporaneous with the sediments are greenstones, tuff, and agglomerates. Locally, fossiliferous limestone is present in scattered outcrops. Other rocks of uncertain relationships include biotite slates and chlorite schists representing green schist facies metamorphism.

The lack of persistent horizon markers in the Cache Creek Group makes determination of the stratigraphy and structure difficult. The rocks have been severely deformed by complex folding and faulting. A large number of fossil collections were made from these rocks; however the fossils which were poorly preserved, showed a wide variation in age from Mississippian to Permian. According to Cockfield (1948) cephalapods dated by Miller and Warren (1933) as mainly Permian, provided the most reliable age for that part of the group.

The younger Nicola Group rocks and the Cache Creek Group have similar lithologies, making it difficult to determine the boundaries between

TABLE 2

TABLE OF FORMATIONS

<table>
<tr><th>Era</th><th>Period or epoch</th><th colspan="2">Formation</th><th>Lithology</th></tr>
<tr><td rowspan="5">Cenozoic</td><td>Pleistocene and Recent</td><td colspan="2"></td><td>Alluvial stream and fan deposits lacustrine, glacio-lacustrine, glacio-fluvial and till</td></tr>
<tr><td colspan="4">UNCONFORMITY</td></tr>
<tr><td rowspan="3">Eocene (50 m.y.)*</td><td rowspan="3">Kamloops Group</td><td></td><td>Basalt, andesite, rhyolite tuff, breccia and agglomerate</td></tr>
<tr><td>Tranquille beds</td><td>Shale, sandstone, conglomerate coal seams and bentonite tuff</td></tr>
<tr><td>Coldwater beds</td><td>Coal, shale, sandstone and conglomerate</td></tr>
<tr><td colspan="5">NOT IN CONTACT</td></tr>
<tr><td rowspan="11">Mesozoic</td><td rowspan="2">Lower Cretaceous or later</td><td colspan="2">Kingsvale Group (80 m.y.)*</td><td>Andesite, basalt, rhyolite, tuff, bentonite, pyroclastic and agglomerate</td></tr>
<tr><td colspan="3">UNCONFORMITY</td></tr>
<tr><td>Lower Cretaceous</td><td colspan="2">Spences Bridge Group</td><td>Basalt, tuff, agglomerate sand-stone, arkose and conglomerate</td></tr>
<tr><td colspan="4">NOT IN CONTACT</td></tr>
<tr><td>Middle and Upper Jurassic</td><td colspan="2"></td><td>Shale, sandstone and conglomerate</td></tr>
<tr><td colspan="4">EROSIONAL CONTACT</td></tr>
<tr><td>Late Upper Triassic to Lower Jurassic</td><td colspan="2">Guichon Creek batholith (198 m.y.)*</td><td>Granite, granodiorite, diorite, quartz diorite and quartz monzonite</td></tr>
<tr><td colspan="4">INTRUSIVE CONTACT</td></tr>
<tr><td>Upper Triassic</td><td colspan="2">Nicola Group</td><td>Feldspathic rock, basalt, limy and undifferentiated non-limy rocks</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="5">UNCONFORMITY</td></tr>
<tr><td>Palaeozoic</td><td>Permian and (?) earlier</td><td colspan="2">Cache Creek Group</td><td>Argillite, quartzite, conglomer-ate, greenstone, tuff, limestone, slates and chlorite schists</td></tr>
</table>

* K-Ar Age determinations

the two groups. Cockfield (1948) chose the base of the Nicola greenstone or the basal conglomerate of Nicola rocks to separate the groups.

Nicola Group. Nicola Group rocks, economically significant because they are host to the Craigmont mineralization, have been studied extensively by Carr (1960) and members of Craigmont's geologic staff. Dawson (1877) who first located the type section ten miles east of Craigmont on Nicola Lake, named and described this group. Nicola rocks are extensively distributed in an area 45 miles wide and 120 miles long in the south central portion of British Columbia as shown in Figure 3.

Carr (1960) subdivided the Nicola Group into four general mapable units shown in Figure 4. The main unit is "feldspathic" rocks consisting of tuffs, tuff breccia and volcanic conglomerate. These dense rocks are characterized by their purple-red color. Closely associated with the feldspathic rocks is a diagnostic labradorite and hornblende rich basalt flow up to 50 feet thick that has been traced continually for several thousand feet. The "limy" rocks mapped by Carr are gradational between pure limestones, limy tuffs and limy argillites. The "undifferentiated non-limy" rocks contain a wide variety of lithologies. Lithic tuffs characterized by abundance of volcanic rock fragments are the most abundant. Well foliated vitric tuffs and porphyritic quartz tuffs also occur in the area. Other rock types mapped by Carr in this undifferentiated unit are tuffaceous greywacke containing fine grained, well sorted volcanic detritus, greywacke composed of lithic and crystal fragments, and an argillite with

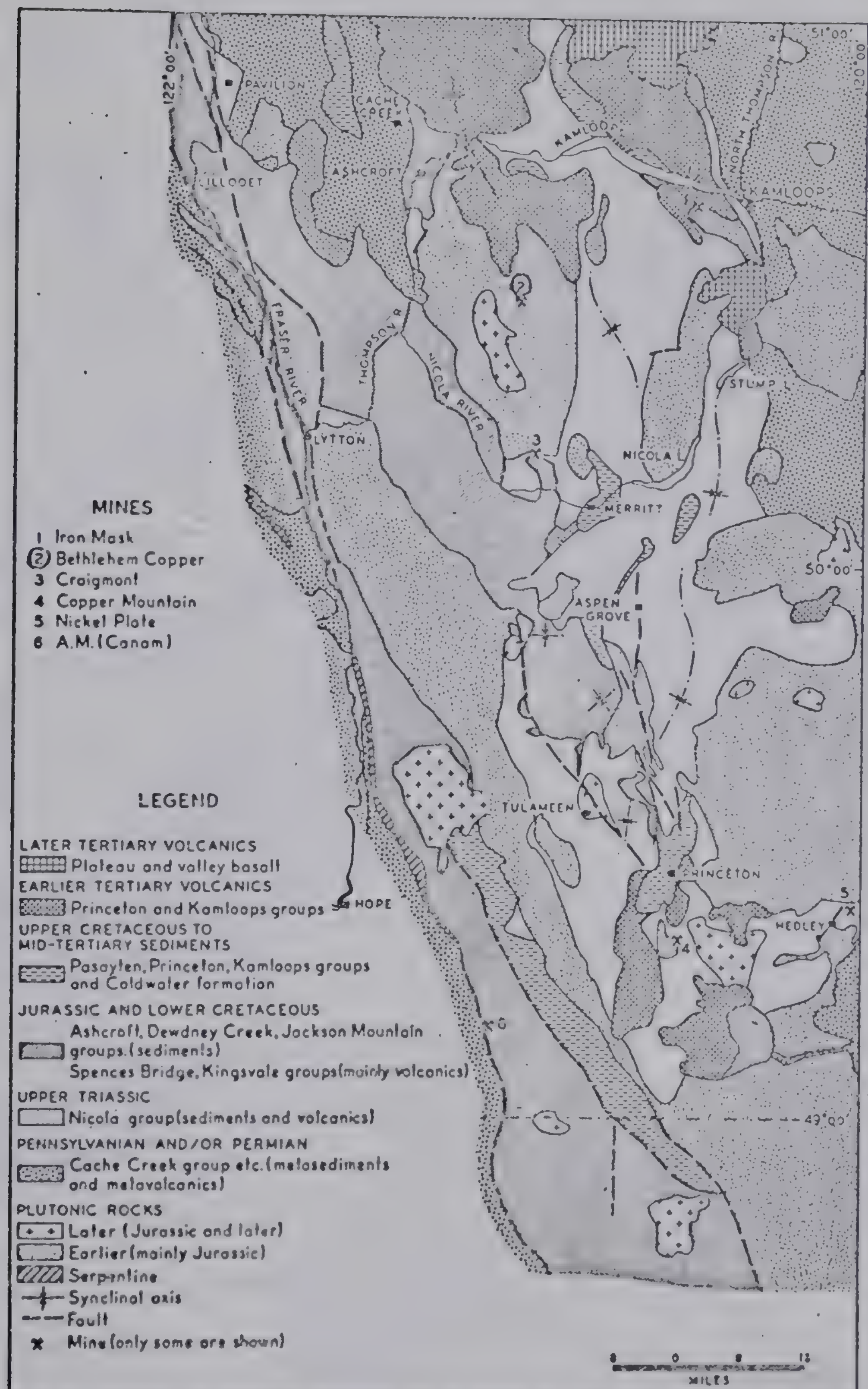


Figure 3. South central area, British Columbia, showing general geology (from Carr, 1962).

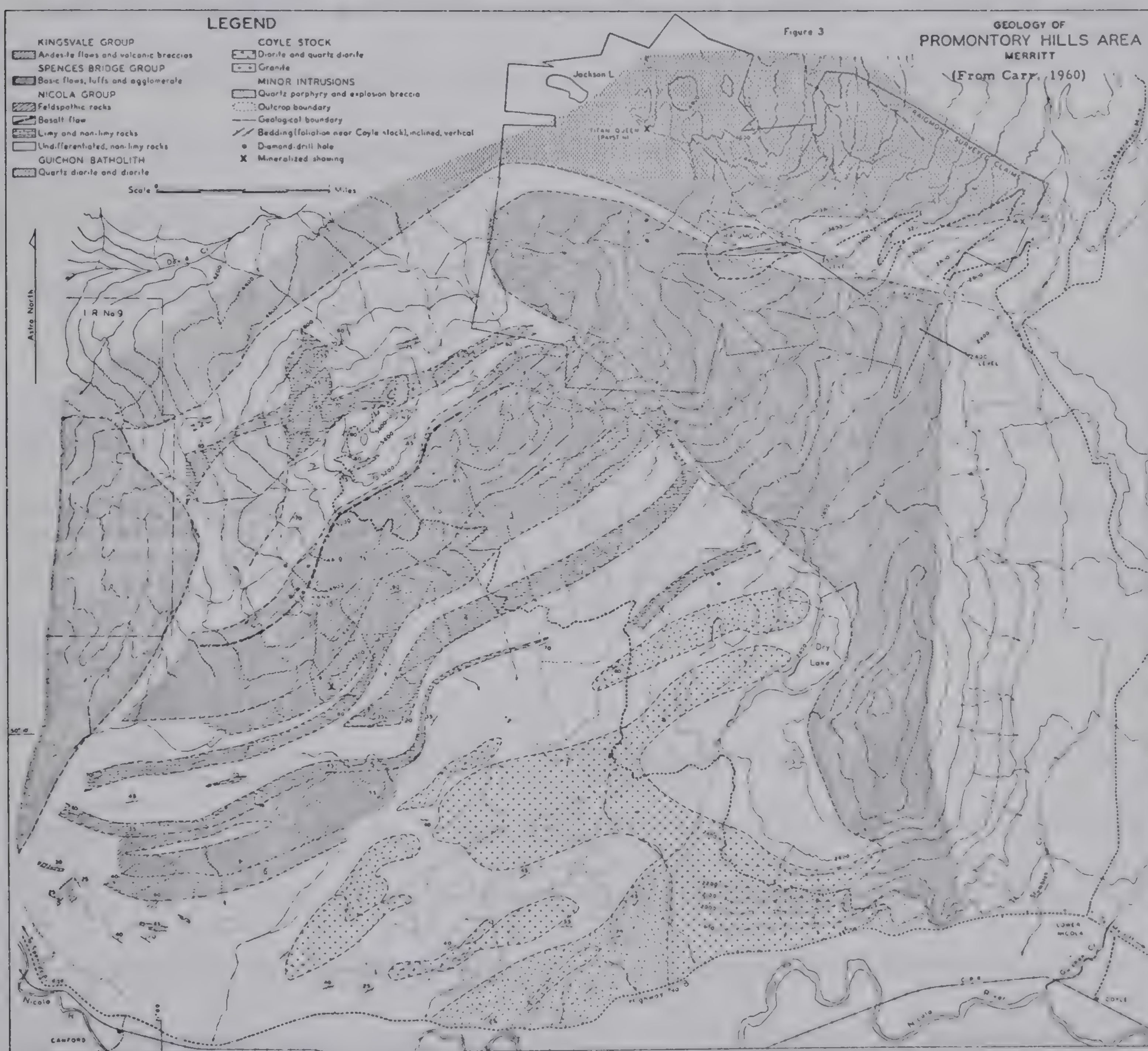


Figure 4. Geology of Promontory Hills area, Merritt (from Carr, 1960).

disseminated pyrite.

Due to the inconclusive nature of the Nicola Group stratigraphy, the structure is not well established. The best defined structure is around the southern margin of the Guichon Batholith where the Nicola rocks dip southerly and strike parallel to the intrusive. Further south the dip steepens and the structure becomes more complex. Nicola rocks are discontinuously faulted parallel to the bedding. Folding on a small scale with minor drag folds are found in some limy rocks on Promontory Hill and at Craigmont.

Based on the Pelecypod Halobia found in limestones on Promontory Hill, Nicola rocks have been assigned to the Karnian stage of Upper Triassic (Carr, 1960). Other poorly preserved corals, bryozoa and gastropods reported by both Cockfield (1948) and Drummond (1965) provisionally support the Triassic age.

Guichon Creek Batholith. The Guichon Creek batholith is one of many plutons situated in south central British Columbia. Cockfield (1948) named the Guichon Creek batholith during his mapping of the Nicola area. This batholith is elongated 40 miles in a northeasterly direction and varies up to 16 miles wide. The boundaries of the batholith are topographically defined to the west by valleys of the Thompson and Nicola Rivers and to the east by Guichon Creek.

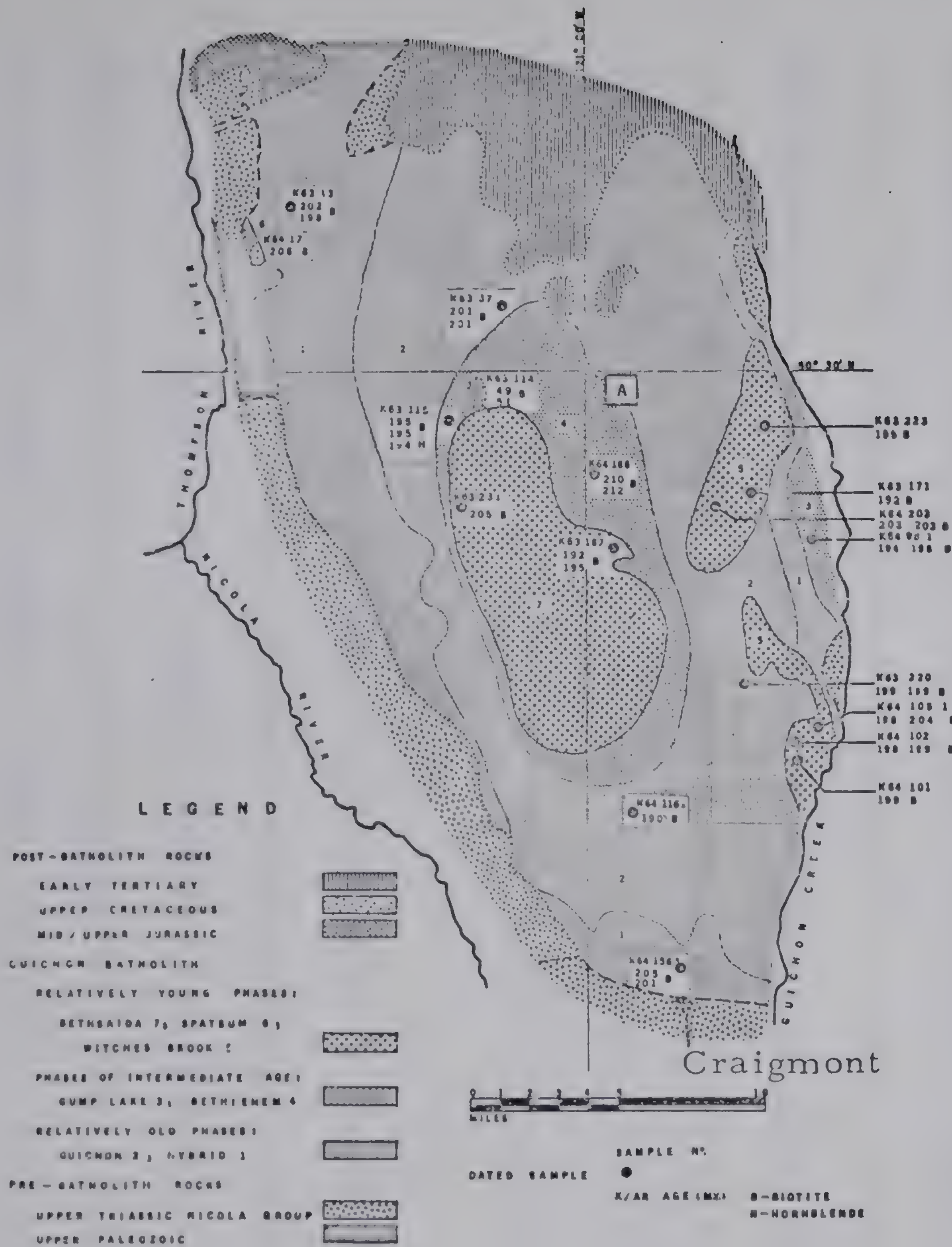
Guichon Creek Batholith geology has received considerable attention beginning with Cockfield (1948) and Duffel and McTaggart (1952). The

first detailed mapping was by White et al., (1957) in the vicinity of Bethlehem Copper's property. Carr (1960, 1963) detailed the southern and western extremities of the batholith. Recently, Parry (1964) studied the specific gravity of batholith rocks, and Dirom (1965) dated, by K-Ar methods, some phases of the rocks near Bethlehem's property. White et al., (1967) and Northcote (1968) described in more detail the geology of the whole batholith and included K-Ar age determinations.

According to Northcote (1968) the Guichon batholith is a semi-concordant composite intrusive pluton with seven nearly concentric phases. The mechanism of emplacement is possibly a combination of magmatic stoping, assimilation of wallrock material, and forceful intrusion.

Figure 5 shows a generalized plan of the batholith geology with mappable phases. In comparing the different phases, remarkable similarity is seen in composition. The main differences are in minerals, textures, and field relationships. Generally the batholith rocks, which vary from equi-granular to porphyritic, range in composition from quartz diorites to quartz monzonites (White et al., 1967).

Guichon rocks closest to Craigmont Mines, mainly quartz diorites, were mapped by Northcote (1968) and named the "hybrid phases." This phase, which forms the outer periphery of the batholith, is gradational in composition toward the periphery due to assimilation of pre-batholithic rocks. Designation of a typical "hybrid" rock is difficult (Northcote, 1968) due to variations in texture and composition resulting from country rock contamination.



PHASES AND VARIETIES OF INTRUSIVE ROCK

Relatively Old

(1) Hybrid - quartz diorite, granodiorite, quartz monzonite

(2) Guichon - granodiorite, quartz monzonite

Intermediate

(3) Gump Lake - quartz monzonite, granodiorite

(4) Bethlehem - granodiorite, quartz monzonite

Relatively Young

(5) Witches Brook - granodiorite

(6) Spatsum - granodiorite

(7) Bethsaida - granodiorite, quartz monzonite

Figure 5. Guichon Creek Batholith, British Columbia, showing general geology (from White et al, 1967).

At the Craigmont Mine discordance of the batholith is illustrated where Nicola rocks are intruded (Rennie, 1962). Along the southern margin of the batholith west of Craigmont, concordant relationships are suggested by the Nicola rock striking parallel to and dipping away from the edge of the batholith (Carr, 1960). Concordance is also suggested by elongation of the batholith parallel to the general northerly structural grain of the country rock (Northcote, 1968). However, truncation of bedding by intrusive rock along the batholith's edge is common. Other structural features of the batholith include foliation, joints, faults and xenoliths.

On the basis of geologic evidence the Guichon Creek batholith is older than Middle Jurassic and younger than Late Triassic. Along the west margin of the batholith (Carr, 1963) and at the Craigmont mine (Rennie, 1962) "hybrid" rocks intrude the Nicola Group. A xenolith of Nicola rocks was found by Northcote (1968) within the batholith on the west side of Glassy Mountain. Approximately five miles south of Ashcroft the Guichon batholith is overlain by rocks of Middle and Late Jurassic age, determined by relative ages of pelecypod and ammonite fossils (Duffell and McTaggart, 1952).

The first potassium-argon age determination of the batholith was made by Baadsgaard et al., (1961) and a date of 186 m.y. $\pm$ 5 m.y. obtained. Subsequently the Geological Survey of Canada published 11 K-Ar dates averaging 240 m.y. and ranging from 224 m.y. to 265 m.y. (Wanless et al., 1965). Northcote (1968) completed 26 K-Ar age

determinations averaging 198 ± 8 m.y. for various phases of the batholith, and Dirom(1965) made 11 determinations averaging 195 m.y., in close agreement with Northcote's (White et al., 1967).

The Geological Survey of Canada's dates have recently been revised (personal communication, R.K. Wanless) from the geologically unsuitable K-Ar dates averaging 240 m.y. to new dates ranging between 184-197 m.y. These recent age determinations for the Guichon Batholith now fit into the accepted geologic history for the area.

Northcote's (1968) mapping showed that the Guichon Creek batholith is progressively younger toward its core, but he was unable to discern this trend with his K-Ar age determinations. To explain the similarity of ages for different batholithic phases Northcote suggests the phases were hot at approximately the same time and began to retain argon simultaneously. He believes the Guichon Creek batholith was emplaced by a combination of mesozonal to epizonal conditions which support the concept that all the phases were hot at one time. The argument that the similarity of ages could be caused by resetting of the K-Ar clock by a regional or thermal metamorphic event is not substantiated by the unaltered older country rocks. Rubidium-strontium whole rock age determinations for the various batholithic phases could possibly distinguish age differences if the length of time between the intrusion of the phases was sufficient. Rubidium-strontium whole rock dating can be used to measure age of crystallization or original emplacement. In comparison K-Ar often

measures metamorphic events if they have occurred. If intrusion of the phases lasted a measurable length of time, then it is feasible that younger phases might have caused an argon loss in the older phases. Updating of older phases might have taken place and K-Ar ages similar to those obtained by Northcote would be the result.

Prebatholithic rocks intruded by the Guichon batholith are thermally metamorphosed at the contacts. The degree of metamorphism diminishes progressively from the contacts. The narrow aureole of metamorphism which varies around the batholith margin includes albite-epidote hornfels, hornblende hornfels and epidote skarn (Northcote, 1968).

The only other significant intrusive rocks close to Craigmont are found five miles south from the southern end of the Guichon Creek batholith. The Coyle stock which intrudes Nicola rocks consists mainly of quartz diorite and discordant bodies of granite (Carr, 1960). Studies of this stock are hampered by covering of surficial valley deposits and Kingsvale volcanics. Numerous basalt and andesite dikes are found in all rock groups with the exception of the Kingsvale which they resemble.

Jurassic rocks. Approximately five miles south of Ashcroft, the Guichon Creek batholith is overlain unconformably by rocks of Middle and Late Jurassic age. First studied in detail by Crickmay (1930) they outcrop in a belt 15 miles long in the Ashcroft area. The main rock types are conglomerate, sandstone and interbedded fossiliferous black

shale. The basal conglomerate contains boulders of typical Guichon quartz diorite, finer grained porphyritic quartz diorite, quartz porphyry and feldspar porphyry (Carr, 1963). With the exception of the massive conglomerates the Jurassic rocks were highly deformed.

According to Crickmay (1930) the base of the succession contained the pelecypod Pleuromya rhynophoria and ammonites Fontannesia cf. carinata indicating an early Middle Jurassic age. Fossils collected by Duffel and McTaggart (1952) provisionally support this age.

Spences Bridge Group. Dawson in 1896 first described the Spences Bridge Group rocks which outcrop four miles southwest of Craigmont where they unconformably overlay the Guichon batholith. They generally consist of basaltic flows, tuffs, agglomerates, sandstones and arkoses. Pebbles and boulders attributed to the Guichon batholith have been found in the Spences Bridge rocks (Cockfield, 1948). These rocks which trend northwesterly have been only slightly deformed and often are horizontal.

Plant fossils, from the Spences Bridge Group west of the batholith, found in argillites and arkoses indicate an age of Aptian or Early Lower Cretaceous (Duffel and McTaggart, 1952).

Kingsvale Group. Kingsvale Group rocks unconformably overlay the Nicola rocks and the Guichon batholith at the Craigmont mine. This group of volcanic rocks consists of andesites, basalts, tuffs, pyroclastics with some bentonites. Above the Craigmont orebody the

Kingsvale rocks are unmineralized. Their distribution is considerably more extensive west and south of the mine area. Fragments of Nicola and batholithic rocks have been found within the Kingsvale (Cockfield, 1948).

Age determinations on well preserved plant fossils found by Rice (1948) in Kingsvale rocks to the south established the age as Late Lower Cretaceous (Albian). Duffel and McTaggart (1952) collected a similar group of plant fossils and arrived at an identical age. A K-Ar age determination from an "argillized vitrophyric biotite andesite" of the Kingsvale yielded a date of 80 m. y. (Lowden, 1963). The sample collected 50 feet above the Nicola surface near the Craigmont mine suggests a minimum age of Upper Cretaceous for the Kingsvale.

Kamloops Group. This group proposed by Cockfield (1948) includes all Tertiary rocks which are present in the area. At Merritt the Coldwater beds consist of sandstone, shale, conglomerate and coal beds that have been mined. The tuff bearing Tranquille rocks overlay the Coldwater beds unconformably. The tops of many hills in the area are capped with nearly horizontal volcanics, the youngest rocks of the Kamloops Group. Feeder dikes for these volcanic flows intrude the Coldwater rocks and the Guichon batholith. Near Merritt members of the Kamloops Group are found unconformably on the Nicola Group.

An age of Eocene is indicated by plant fossils and pollen found in the Coldwater beds (Hills, 1965). Recent K-Ar age determinations from

fragmental rhyolite present in Highland Valley indicate an age of 50 $\pm$ 3 m.y. or Eocene (White et al., 1967). This agrees closely with four age determinations from bentonites within the Tranquille beds northwest of Kamloops giving an average age of close to 50 m.y. (Hills and Baadsgaard, 1967).

Mine Geology

Introduction. All rocks within the Craigmont mine area except some younger intrusive rocks have been metamorphosed to varying degrees by intrusion of the Guichon Creek Batholith. Because of their indistinct character, the variably altered Nicola rocks have been named differently by workers. The geology staff at Craigmont has adopted a classification that permits mapping and assignment of rock names from megascopic identification. Drummond (1966) in his detailed petrological study of Craigmont rocks proposed slightly different terminology. Greater refinement in recognizing differences in rock types was one result of his microscopic study.

For this study only specimens of major rock types were collected. A detailed petrologic or mineralogic project on Craigmont rocks was not attempted. The following description of petrology and mineralogy is based on the work of Drummond (1966), Keevil (1965), Carr (1966), Rennie (1962) and Bristow (1968). This work is supplemented by a recent composite plan of the open pit geology compiled by mine staff, plus a general microscopic study of specimens collected from the

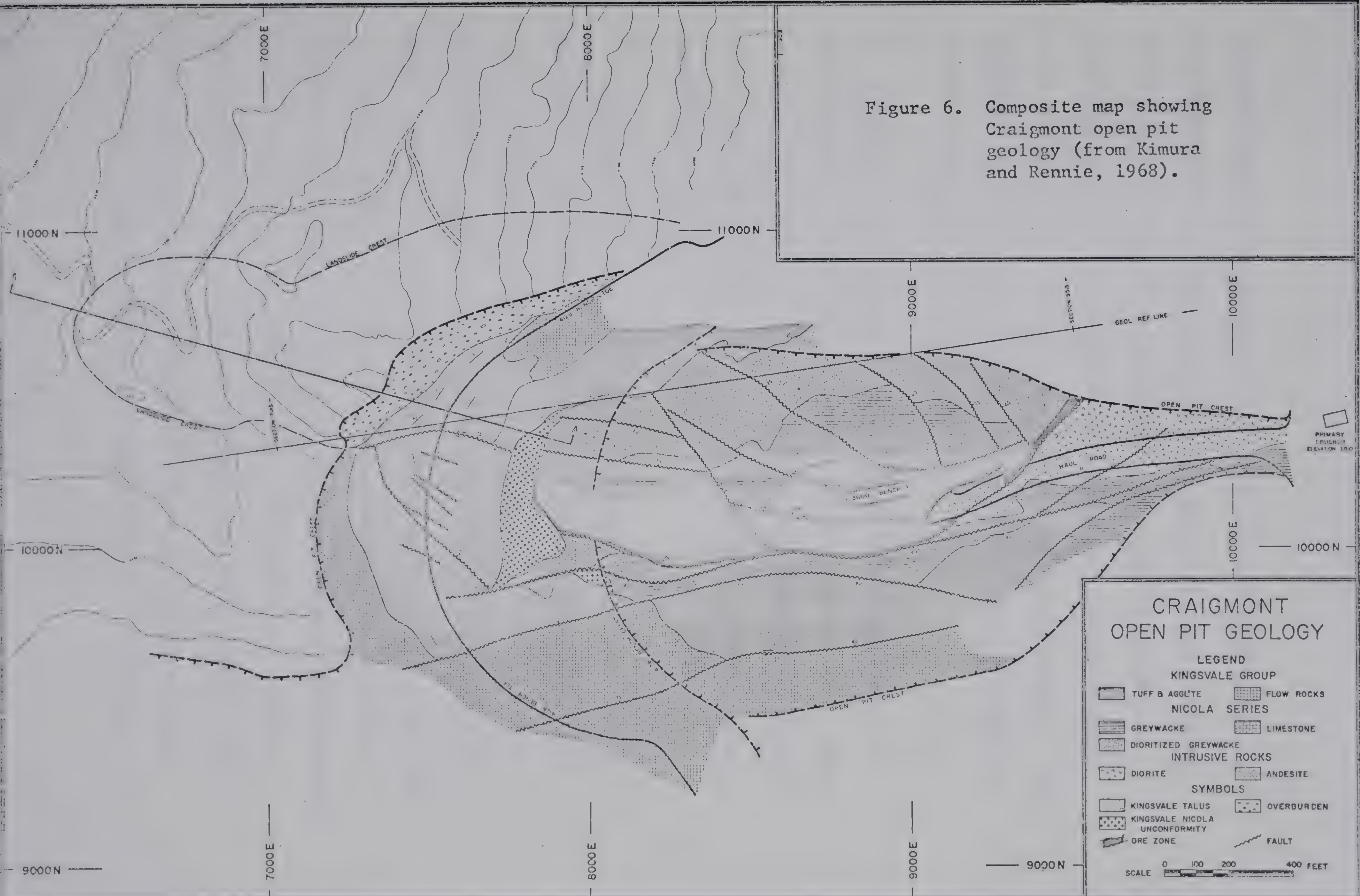
open pit and underground.

Marble. Recrystallized limestone or marble was recognized by Rennie (1962) as the main host rock for Craigmont mineralization. Marble is mapped as a separate unit at the mine if skarn minerals such as garnet, epidote, or actinolite are not abundant. At Craigmont, zones of massive marble, such as shown on the composite open pit map (Figure 6), may be several hundred feet thick and occur adjacent to the main orezone.

Marble near the mine has a much whiter colour compared to unmetamorphosed limestones in the western part of the area. The grain size of the marble varies from coarse to fine-grained. Some marble has foliation, however the calcite crystals, commonly equant, usually form a mosaic texture. Lamellar twinning on all calcite crystals is pronounced. Associated minerals in the marble such as chlorite, quartz, minor feldspar, epidote, actinolite and diopside suggest that metamorphic conditions of albite-epidote hornfels facies altered these rocks (Drummond, 1966).

Argillite. Since argillite is not a common rock within the mine, the geologic staff map it with the greywacke group. Drummond (1966) recognized a black finely laminated argillite intercalated with fine grained sandstones and greywackes. A typical mineral composition for unaltered argillite would be: 90% of quartz and feldspar with variable amounts of chlorite, biotite, calcite, magnetite and pyrite.

Figure 6. Composite map showing Craigmont open pit geology (from Kimura and Rennie, 1968).



Argillites that have been altered to hornfels are distinguished by development of hornblende up to 25%. The nature of the groundmass and the severe alteration of the feldspar in an argillite hornfels is illustrated on Plate I-4. Occasionally hornblende, chlorite or magnetite are found foliated around aggregates of quartz and feldspar. The argillites, found most commonly in narrow beds at depth, are not considered an important rock type in the mine.

Chert. Fine-grained quartzofeldspathic sandstones which have been hornfelsed are referred to as cherts by Drummond (1966). These rocks, even less common than argillites, are composed of coarse silt to very fine grains of quartz, untwinned plagioclase, chlorite, sphene, apatite and magnetite.

Greywacke-Hornfelsed Wackes. The terms greywacke used by the mine geologists and hornfelsed wackes given by Drummond (1966) are synonymous. Greywacke has been variously defined and the definition which is applicable to Craigmont greywackes is difficult to determine. According to mine geologists it is now used as a "catch all term."

Quartzofeldspathic sediments with varying amounts of biotite, chlorite and possibly hornblende have been metamosphosed to hornblende-hornfels facies of contact metamorphism. The result is a number of distinct hornfels rocks. The most abundant type contains biotite and chlorite, whereas hornblende bearing hornfelses are relatively minor. A lithic wacke hornfels with lithic framents greater than 25% was

recognized by Drummond (1966).

The hornfelsed wackes represent an important rock unit within the mine area, occurring as continuous beds of varying thickness and are closely associated with argillite and skarn rocks.

Minerals of the chlorite and biotite bearing hornfels include quartz, feldspar, biotite, chlorite and muscovite. Textures exhibited by these rocks are variable from schistose to a uniform non-directional texture. Grits (porphyroblasts) of quartz and some feldspar are often found (Plate I-3).

Andesite. Two different andesites are observed within the mine area at Craigmont. The oldest andesite, texturally distinct with euhedral andesine phenocrysts, is part of the Nicola Group and outcrops along the pit southwall. The other, a discordant andesite, intrudes Nicola rocks. This hornfels hornblende andesite contains about 55% andesine plagioclase, 36% hornblende, 4% chlorite, 2% magnetite and 1% biotite. The alignment of microlites in the matrix suggest flowage took place during crystallization. Small hornblende phenocrysts as well as interstitial biotite and quartz are possible evidence for recrystallization and hornfels formation. Andesite belonging to the Nicola Group, most extensive of the andesites, megascopically resembles hornfels argillite as it contains abundant sericite, epidote and chlorite.

Kingsvale volcanics. The Kingsvale volcanics, a thick sequence of andesite-basalts overlay many of the rocks at the mine. To the west

they become increasingly thick creating a major obstacle for prospecting in this direction. With the exception of a few epidote veins, the Kingsvale rocks are not mineralized at Craigmont.

Basalt. The youngest mafic intrusive rocks are dense basalts probably related to Tertiary volcanism. Basalt dikes of this group cut Nicola and some Guichon rocks within the mine area but are rather rare. They contain 5% augite phenocrysts, 40% labradorite microlites and 45% cloudy matrix.

Guichon Diorite (Hybrid rocks). As previously mentioned intrusive rocks affiliated with the batholith periphery are confusing to study because of variations in texture and composition from pre-batholith rock contamination. Within the mine area, variation in the amounts of quartz, potassium feldspar, biotite and hornblende are such that locally rocks grade into diorite, quartz diorite, granodiorite and quartz monzonite. For convenience, the term "hybrid" proposed by Northcote for these rocks will be used.

Most of the hybrid rocks are equigranular and holocrystalline consisting of plagioclase (An 30) usually sericitized. Dark green hornblende crystals, frequently altered to chlorite, form from 15-25% of the total mineral composition of some samples. Quartz generally is not abundant and where present often is interstitial. Chlorite seems to be the alteration product of either biotite or hornblende. Strongly pleochroic epidote is often present within plagioclase crystals.

Accessory minerals are apatite, sphene, magnetite and pyrite. Propylitization, development of epidote, calcite, quartz, sericite and chlorite, has affected all varieties of Guichon rocks within the mine area. The open pit composite geologic map in Figure 6 shows that the Guichon rocks are confined to the northeastern part of the pit. At depth the same relationship exists, however apophyses of dioritic rock intruding the complexly folded Nicola sediments are difficult to trace since cross-cutting relationships are not commonly evident.

Granite. Another distinct intrusive rock in the mine area is a pink hypidiomorphic granite recognized by Drummond (1966). The granite, observed mainly as dikes, cuts both Guichon diorite and Nicola rocks. Perthitic potassium feldspar with twinned microcline, minor oligoclase and interstitial quartz characterize this rock. The accessory minerals are sphene, leucoxene, clinozoisite, magnetite, calcite and pyrite. Drummond showed that the mineral composition of this granite at the mine closely resembles that of the Coyle stock two miles south as shown in Figure 4.

Skarn Rocks

Craigmont geology shows both recrystallized constituents as well as addition of materials from igneous sources. The recrystallization or hornfels development of the sediments has already been discussed. Many examples of classical skarn rocks are found in the literature; however the composition of the skarn at Craigmont makes its character

somewhat unique.

The major skarn minerals extensively distributed in the mine area are epidote, actinolite and chlorite. Pistachio green epidote with a remarkably constant composition is a widely distributed mineral according to Drummond (1966). Also having widespread distribution and constant composition, actinolite has formed interstitially to other minerals. Chlorite, usually closely associated with calcite, has two varieties. They were distinguished by Drummond (1966) by their interference colours and other optical properties. Magnesium chlorite has an abnormal brown interference colour whereas the iron rich variety has an abnormal blue colour.

Garnet, which has a composition approximating the andradite-grossularite series, is found in certain zones in the mine rocks. Variance in composition of the garnets associated with epidote and actinolite was determined by Drummond (1966). Diopside is present in some marble at Craigmont, but is not common.

Common skarn minerals such as wollastonite did not form in the Craigmont skarn despite the fact that quartz and calcite are often adjacent minerals.

The skarn rocks have developed in narrow zones paralleling the boundaries of Guichon rocks. The skarn may be in direct contact with intrusive Guichon rocks, but more often the skarns and Guichon rocks are separated by hornfels rocks. Most of the skarn rocks have associated metallic mineralization although unmineralized skarn rocks to

the west have been found (Keevil, 1965). Weak zoning of the skarn rocks in one section (Figure 7) changes from marble to actinolite-epidote rocks to garnet skarn in downward direction toward the diorite (Drummond, 1966). According to Bristow (1968) lateral zoning along the strike also is found. Along other sections the relationships of the skarn zones are more complex and no trends are obvious.

Metallization

Introduction. Two distinct stages of metallization occurred at Craigmont. Magnetite, chalcopyrite and specularite formed simultaneously with the skarnification. During the second phase, veins containing specularite, chalcopyrite and K-feldspar formed. In some veins platy magnetite is found rather than specularite.

Metallic minerals. Chief metallic minerals at Craigmont are: Chalcopyrite, ($CuFeS_2$), magnetite (Fe_3O_4) and specularite (Fe_2O_3). Small amounts of pyrite and bornite are present as disseminated crystals and trace amounts of hematite, ilmenite and pyrrhotite are also observed.

Chalcopyrite, the only ore mineral, is present in most rocks. This widely disseminated mineral usually is interstitial to other minerals and is fine-grained; this physical character presents problems for the metallurgical staff in obtaining good copper recovery. Massive veins, streaks and patches represent high copper values, thus higher profits for Craigmont when they are mined.

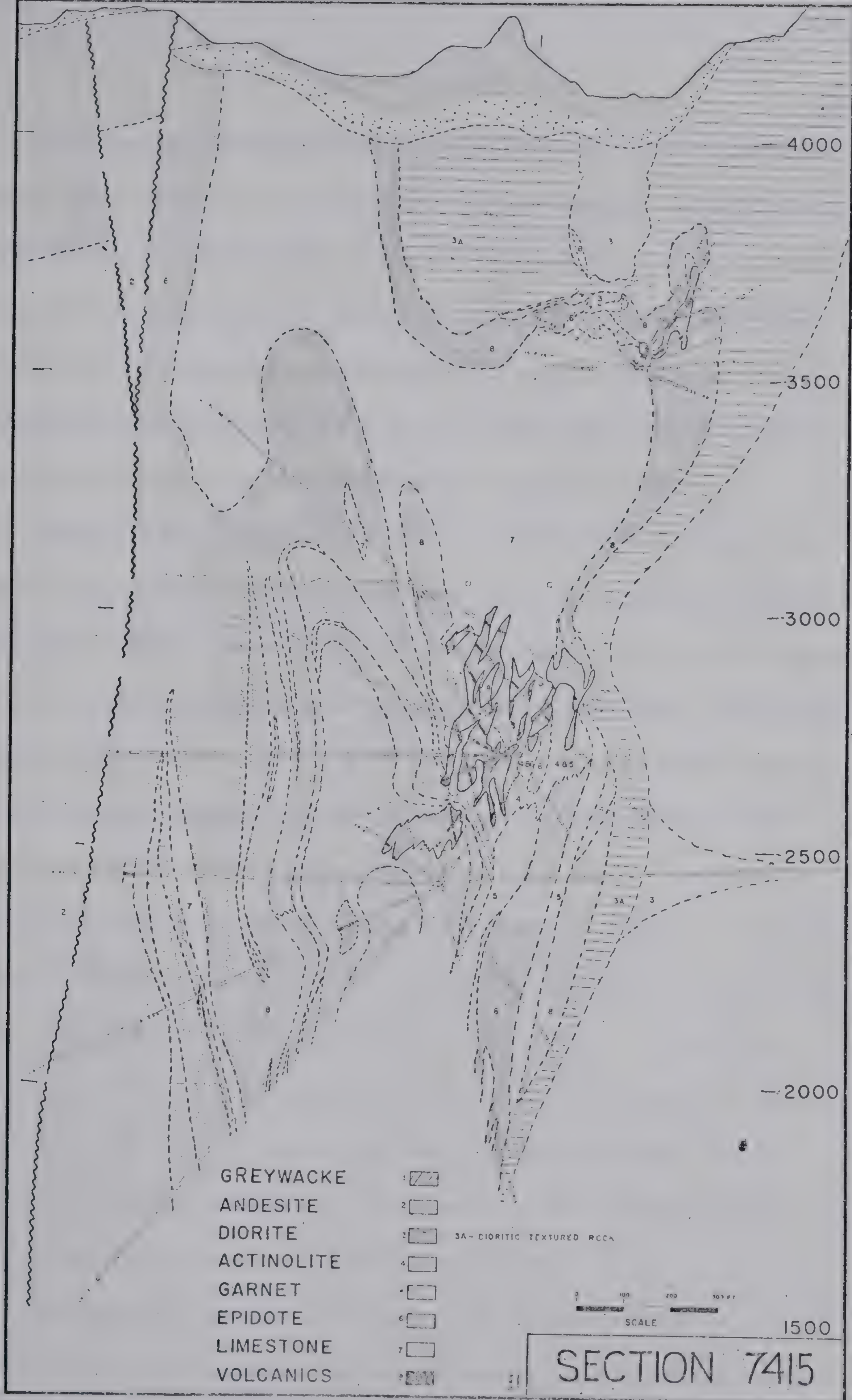


Figure 7. Geological section 7415 from Craigmont showing drag folding on north limb of a large anticlinal fold (from Bristow, 1968).

Chalcopyrite seems to have an affinity for calcite and quartz and is more often observed with magnetite than specularite. Bornite when found is close to chalcopyrite. Plates II-6 and II-7 at the end of this paper show the interstitial nature of chalcopyrite and its association with quartz and magnetite. On plate III-1 narrow stringers of chalcopyrite, that are often displaced a few millimeters by secondary fracturing, are observed along crystal boundaries and fractures.

Magnetite takes a number of forms at Craigmont, frequently as euhedral crystals disseminated in skarn rocks or as massive granular magnetite in pods or lenses. Plates of magnetite with multiple fractures often are found wedged together to become one larger plate. This platy magnetite illustrated on Plate III-1 has either replaced earlier specularite or grown on the basal plane of the specularite. Evidence for magnetite replacing specularite is found on Plate III-7. Magnetite is easily converted to specularite along the octahedral partings and specularite crystals are often reduced to magnetite, wholly or in part (Lindgren, 1933). The magnetite in some polished sections shows anisotropism possibly representing a high temperature of formation. At the Concepcion Del Oro copper mine in central Mexico many similar minerals to those at Craigmont are present, in fact, magnetite is found to replace specularite there (Buseck, 1966).

The magnetite content of the ore zones decreases and the specularite content increases toward the western end of the mine area suggesting some type of zoning of either magnetite or specularite.

Blades, laths or tabular forms of specularite crystals provide some interesting textures. Specularite blades are often variable in thickness and form. They may be bent, straight, cross-cutting, radiating or randomly orientated aggregates (Plates III-3, III-4, III-5, III-6). Schwartz (1951) described specularite textures similar to those at Craigmont as rumpled foliate. Specularite which is anisotropic has a deep internal reflection and some of the curved or deformed crystals show lamellar twinning under crossed nicols (Plate III-8). The twinning probably reflects deformation after or during late crystallization. Drummond believes that in some instances specularite has been reduced to magnetite. Martitization, oxidation of the iron oxides, is believed to have affected some crystals. Two major periods of specularite formation are represented by the disseminations in chlorite, actinolite and epidote skarn rocks and the K-feldspar veins.

Orebodies. Five orebodies contain the major portion of copper at Craigmont. Four interconnected orebodies have been variously called Number 1, Number 2, North Limb and Number 2 Wing by the mine staff. The orebody which occurs separately is the Number 3. This is a small orebody and is unique in that it is composed entirely of chalcopyrite filled fractures in a crackled chert (Bristow, 1968). Together the orebodies extend about 3000 feet horizontally, 1800 feet vertically and across mining widths ranging from 10 to 350 feet (Bristow, 1968). The orebodies as a whole tend to stand vertically,

however some sections indicate a slight southerly dip. The shape of the bodies, presumably controlled by the host rocks and their structure, is irregular with sinuous arms extending out from the main bodies as shown in Figure 7.

All the orebodies with the exception of Number 3 are closely associated with skarn rocks. The skarns, which have sharp contacts, seem to have influenced the distribution of the metallic minerals. The following assemblages of skarn minerals and their association with iron oxides and chalcopyrite presented by Drummond (1966) illustrates this.

1. Garnet-epidote- (actinolite)* -calcite-quartz-magnetite-pyrite.
2. Epidote-actinolite- (garnet) -calcite-quartz-magnetite-specularite-chalcopyrite.
3. Actinolite-epidote- (chlorite) -calcite-quartz-magnetite-chalcopyrite.

The actinolite-rich assemblages have the greatest concentration of chalcopyrite along with iron oxides and quartz. In contrast garnet-rich zones are noticeably barren of chalcopyrite.

Within the orebodies the vertical distribution of copper is not extensive compared to the widespread distribution of iron oxides. Grade of copper in most of the bodies averages close to 2.0% (Keevil, 1965) and the periphery of the bodies would be defined by the underground mining cutoff grade of about 0.7% copper.

*Brackets indicate the minerals are present but in minor quantities.

Structure. In the early stages when the mine geology was first studied geologists believed that the important structural feature was simple faulting. However as experience with geology increased, complex drag folding was proposed to explain the structure. The relationships of the skarn rocks suggest that drag folding was operative. Overall structure still is not clear because other post deformation processes such as mineralization and skarn formation have obscured many primary structural features. Considerable evidence supports the concept of drag folding on the north limb of an anticline as seen in Figure 7. Brecciation in the upper parts of the sections, intrusions of dioritic apophyses along synclinal troughs, and strongly developed foliation striking east-west and dipping steeply south, all support drag folding. Shearing of competent rocks and drag folding of relatively incompetent rocks would be expected especially in an environment next to igneous intrusion such as at Craigmont.

By aligning the antiform structures , Bristow (1968) estimates that folds at Craigmont plunge about 60 to 70^{o} eastward. The folding also seemed to have influenced the intrusion of diorite apophyses and prediorite andesite as well as the orebodies.

Structural control for the skarn distribution is inferred from the common occurrence of skarn along the attenuated lobes of the drag folds. This association is not evident in all sections (Drummond, 1965). Narrow shear zones replaced by the chalcopyrite-specularite-K-feldspar veins cut both the skarn zones and the thermally metamorphosed wall rocks.

The Craigmont orebodies occur within a block bounded on the north and east by the Guichon batholith, on the south by an east-westerly trending regional fault and on the west by a northwesterly trending regional fault. Post mineralization small scale fracturing and faulting has affected all rocks in the mine area. Native copper, hematite and copper oxides have been deposited near surface along some of these young fractures.

Metasomatism and genesis of skarn and metallization. The chemical analyses of skarn rocks and impure limestone (Table 3) suggest that Si, Fe, Mg and S were added to the limestones with a resultant loss of CaO and CO_2. In large skarn zones at Craigmont the processes of metasomatism has been so intense that the original character of the calcareous rocks is no longer recognizable. Fractures and breccia zones must have provided good passageways for fluids and strongly influenced the extent and areas of metasomatism.

The mechanics that allow replacement by metasomatising-mineralizing fluids have been documented by Buseck (1966). Limestone when heated expands permanently with subsequent increase in permeability. This increase in permeability allows fluids to travel and react with the carbonate rock, depositing silicates and dissolving CO_2, thereby increasing rock porosity and brittleness. The high temperatures during replacement facilitated the formation of the metasomatic minerals. The porosity of the skarns allowed the contemporaneous mineralizing

TABLE 3

CHEMICAL ANALYSES OF LIMESTONE, SKARNS AND K-FELDSPAR ALTERED SKARN ROCKS (from Drummond, 1966)

	A	B	C	D
SiO_2	16.56	35.66	41.32	45.54
TiO_2	0.16	0.18	0.41	0.20
Al_2O_3	3.49	4.09	7.16	9.05
Fe_2O_3	1.33	19.58	13.51	8.45
FeO	1.28	20.06	3.08	13.50
MnO	0.13	0.13	0.41	0.13
MgO	1.49	6.00	1.76	4.79
CaO	43.30	8.96	28.58	6.40
Na_2O	0.22	0.17	0.27	0.24
K_2O	0.42	0.35	0.07	5.40
P_2O_5	0.10	0.20	0.18	0.21
CO_2	30.59	1.25	2.41	1.74
H_2O-	0.04	0.03	0.13	0.09
H_2O-	0.71	1.20	0.78	1.02
S	-	1.92	-	3.00
Total	100.07	99.78	99.82	99.76

A. Impure marble, bulk sample

B. Actinolite-epidote skarn, bulk sample

C. Garnet-epidote-actinolite skarn, bulk sample

D. K-feldspar alteration in actinolite-epidote skarn, bulk sample

fluids to permeate the rock and locally fill vacant spots and to replace some skarn minerals. As the nearby intrusive rocks began cooling, stresses were increased and much local fracturing within the brittle contact rock continued permitting further passage of metasomatising-mineralizing fluids. At Craigmont this stage is represented by specularite-K-feldspar-chalcopyrite veins that cut skarn rocks.

The metasomatism seems to have taken place under conditions of hornblende-hornfels facies based on presence of grossularite-andradite garnet and diopside. This facies represents a wide range of temperatures from 550-700°C and water pressure of 1000-3000 bars (Turner and Verhoogen, 1960). Northcote (1968) believes that the maximum temperature along the batholith periphery was no greater than 550°C based on the presence of albite-epidote hornfels and hornblende facies rocks. Evidence which contradicts both of these estimates is the absence of wollastonite pointing to temperatures of about 300°C during skarn formation.

Several reactions involving one or more vapor phases took place during skarn formation and metallization. The vapor phases H_2O, CO_2, O_2 and S_2 were present in sufficient quantities to allow the chief minerals to form. Isotopic evidence to be discussed in detail in a following section indicates that both the metasomatising and metal bearing fluids have mainly ascended. There is no evidence for a distinct time break between silicification and deposition of magnetite, specularite and chalcopyrite that are disseminated in the skarn rocks. It is likely that

fluids having similar origins altered only by their interaction with the country rock brought about both skarnification and ore deposition.

The contemporaneity of some minerals such as magnetite and specularite requires fluctuations of temperature or fluctuations between reducing and oxidizing conditions during iron oxide deposition. Reactions were slightly different during the later veining of the skarn rocks by K-feldspar, specularite and chalcopyrite assemblages. These slightly younger veins with their metallic and gangue components have had chemical increases in K_2O, Al_2O_3 and SiO_2 compared to the bulk composition of the skarn rocks (Table 3). This and the formation of anhydrous iron oxides suggest that chemical, temperature and pressure conditions varied only slightly during skarnification and metallization. Other evidence for slightly variable conditions is that there has not been any complex introduction of elements adjacent to the Guichon batholith by pneumatalytic and hydrothermal agents.

The addition of K_2O, Al_2O_3 and SiO_2 to the Craigmont rocks during the veining episode is possibly explained by alkali chloride solutions producing variations mainly in K-feldspar relative to plagioclase and enriching the rocks in K-feldspar at temperatures below about 475°C (Burnham, 1967, p. 59).

Controls of mineralization. The only feature consistently linked with the orebodies and associated metallic occurrences is the metasomatic aureole adjacent to the Guichon rocks. Within the skarn aureole

certain calc-silicates might have localized the ore selectively or may just reflect contemporaneity rather than selective replacement. Fissures, the result of the drag folding, were likely an important control initially whereas secondary cross faulting has controlled the younger mineralization. Another possible control of mineralization was the presence of carbonate rock and skarn at Craigmont; however, the Number 3 orebody which is found in neither carbonate or skarn rocks poses some problems for this theory.

Classification. The contemporaneity of the Guichon Batholith emplacement and ore mineralization, the ore mineralogy, abundance of skarn and proximity to igneous contacts of the Craigmont deposits places them into the contact metamorphic class of ore deposits as defined by Lindgren (1933).

CHAPTER IV

ISOTOPE GEOLOGY

Geochronology

Introduction. Radiometric dating was used to determine the age and genesis of Craigmont mineralization and relationship of the Guichon Batholith to the orebodies. Six whole rock samples were dated by the rubidium-strontium isochron method. These included four of potassium feldspar rich gangue from the orezone and two of quartz monzonite from the northern part of the Guichon Batholith. The K-feldspar gangue is contemporaneous with the second phase (veining phase) of mineralization and is associated with specularite and chalcopyrite. Sample descriptions and locations are outlined in Table 4.

The theoretical basis of the rubidium-strontium whole rock isochron method has been described in detail by Baadsgaard (1965) and Hamilton (1965). To summarize, all samples were analyzed for $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios. By plotting $^{87}Rb/^{86}Sr$ versus $^{87}Sr/^{86}Sr$, a whole rock isochron plot (Compston and Jeffery, 1961) is obtained. Samples that have the same age (but vary in rubidium content) will plot on a straight line of slope $(e^{\lambda t} - 1)$. The basic isochron equation is:

$$(^{87}Sr/^{86}Sr)_t = (^{87}Sr/^{86}Sr)_o - (^{87}Rb/^{86}Sr)_t \; (e^{\lambda t} - 1)$$

where t refers to the time elapsed from t = O, the time of formation of the rock, and λ is the decay constant for ^{87}Rb. For this study the ^{87}Rb decay constant used is 1.39×10^{-11} years.

A brief discussion of the methods of sample preparation and isotope measurement is given in Appendix B.

TABLE 4

PETROGRAPHIC DESCRIPTIONS AND LOCATIONS OF SAMPLES

USED FOR RB - SR DATING

6243 Potassium feldspar gangue

Location: 10,300N; 9370E; 3600' elev. - open pit

Description:

The specimen is coarse-grained, pink colour and holocrystalline. Perthite (K-feldspar with intergrown plagioclase) is present with minor amounts of coarse microcline and plagioclase. The feldspars which comprise 85-90% of the specimen are cloudy and often iron stained. Fine-grained quartz is found interstitial to the feldspar. Minor disseminations of chalcopyrite and specularite with trace amounts of calcite, chlorite, epidote, sphene and actinolite comprise the other minerals.

6250 Potassium feldspar gangue

Location: 10,140N; 8320E; 3534' elev. - open pit

Description:

The specimen is coarse-grained, buff to pink in colour, holocrystalline and comprised of inequigranular crystals, predominantly cloudy grains of K-feldspar with minor amounts of perthite and microcline. Together the feldspars comprise about 90% of the specimen. Vermicular textured intergrown quartz and K-feldspar is present in small amounts. Individual quartz grains comprise about 8% of specimen. Trace amounts of epidote, chlorite, chalcopyrite and specularite are present.

6259 Potassium feldspar gangue

Location: 3590' elev. at 771 Ore Pass - underground

Description:

The specimen is fine to medium-grained, reddish buff coloured and holocrystalline. K-feldspar 45% of total with 25% quartz are intergrown forming a graphic texture. Some coarse grains of untwinned feldspar and quartz in about equal amounts form the remainder of specimen. Trace amounts of epidote, chlorite and apatite are present. Specimen is from vein about two feet thick.

6271 (AK209) Potassium feldspar gangue

Location: 3500 Level near entrance - underground

Description:

Specimen is medium to coarse-grained consisting of pink, fragments (breccia) of cloudy feldspar with massive interstitial euhedral magnetite. The cloudy K- feldspar which comprises about 50% of specimen contains disseminated euhedral crystals of magnetite and actinolite with minor amounts of sericite. Other minerals and their approximate abundance are: magnetite - 20%, quartz - 10%, calcite - 10%, and trace amounts of chlorite, epidote and chalcopyrite.

66-58A Quartz monzonite variety of Guichon Batholith

Location: 121° 13' W; 50° 34' N; On Highland Valley road 13.1 miles south of town of Ashcroft

Description:

Specimen is medium-grained holocrystalline and the crystals are inequigranular and hypidiomorphic. It is comprised of 40% quartz, 20% K-feldspar and 30% plagioclase (Oligoclase). The K-feldspar is cloudy compared to plagioclase and usually is sericitized. A few grains of perthite are also present. Biotite 2-5%, and trace amounts of chlorite, sphene, epidote, magnetite and sericite make up the remainder of the minerals.

4011A Quartz monzonite-granodiorite variety of Guichon Batholith

Location: 120° 51' W; 50° 29' 30" N

Description:

This medium-grained holocrystalline specimen is comprised of about 55% quartz, 20% highly sericitized cloudy K-feldspar and 20% sodic plagioclase that is relatively unaltered and often shows albite twinning. Biotite averages about 5%. The remainder is made up of trace amounts of magnetite and epidote, the latter occurring as small veinlets.

Results

The six analyzed samples form an isochron which gives a date of 198 million years and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7040 $\pm$ 0.0002. The analytical data is shown in Table 5, and the isochron plot in Figure 8. The samples show excellent colinearity. The standard deviation of linearity of the isochron is $\pm$ 0.4 m.y.. This small deviation falls well within usual analytical error limits. Replicate analyses at the University of Alberta geochronology laboratory yield variance estimates for Sr^{87}/Sr^{86} and Rb^{87}/Sr^{86} such that the error could be about $\pm$ 5 m.y. and still fall within general error limits.

The date of 198 m.y. agrees closely with University of British Columbia and Geological Survey of Canada's potassium argon dating of the Guichon Batholith (see discussion in Chapter III). This agreement and the colinearity of samples leads the writer to accept the present finding of the age of Craigmont mineralization. A genetic relationship between the Craigmont mineralization and the Guichon Batholith is implied by their contemporaneous formation.

The duration of mineral formation or time interval between emplacement of intrusive rocks and spatially related mineralization has been determined for other ore deposits (Ohmoto et al., 1966; McDowell and Kulp, 1967; Moorbath et al., 1967; Livingston, 1968). These studies dealing mainly with ore deposits younger (Cretaceous-Tertiary) than Craigmont, have found time intervals between emplacement of intrusive rocks and mineralization ranging up to 4 m. y with

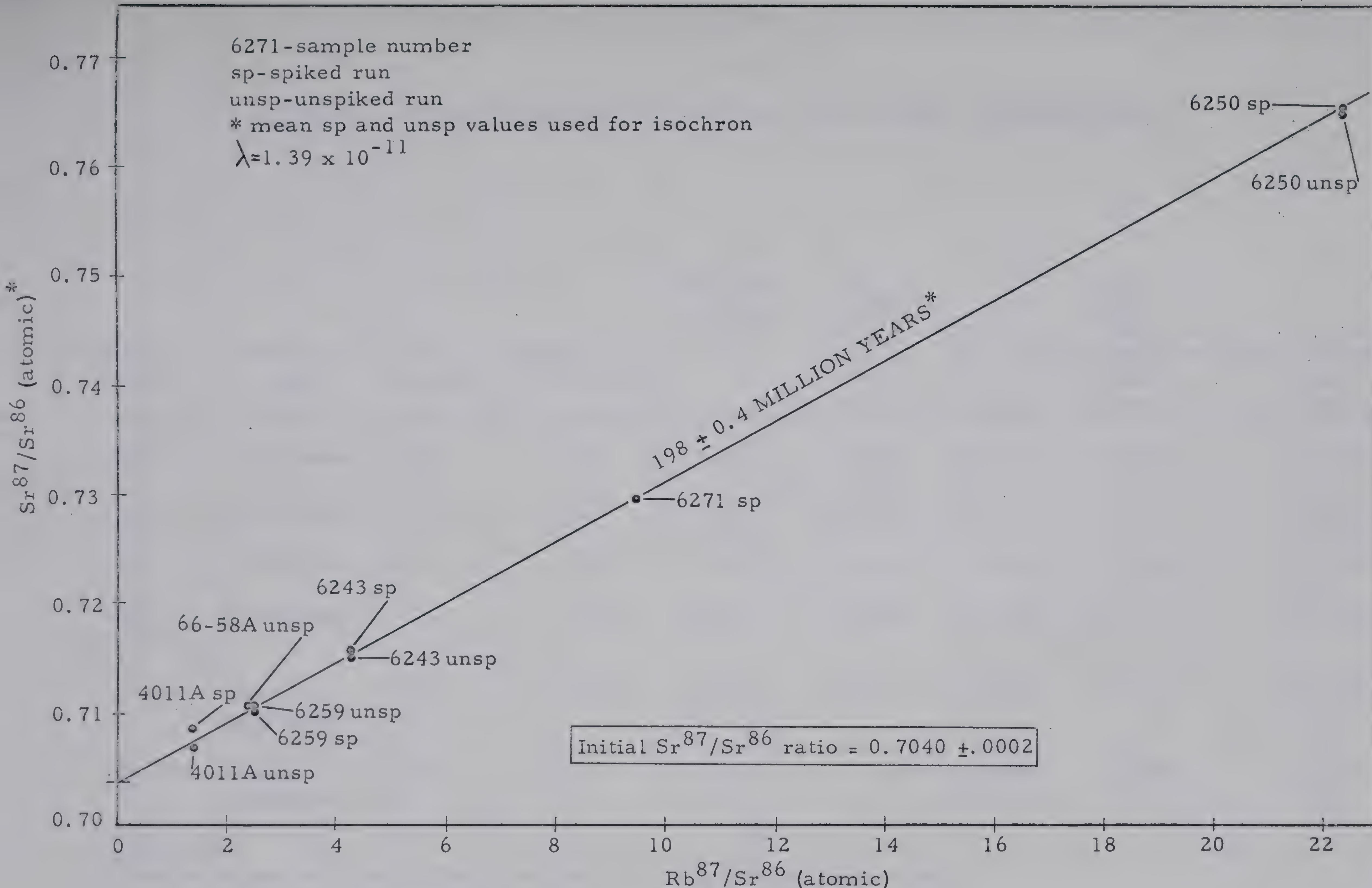


Figure 8. Rb-Sr isochron for K-feldspar samples from Craigmont Mine and Guichon Batholith whole rock samples, British Columbia.

TABLE 5

RUBIDIUM-- STRONTIUM ANALYTICAL DATA FOR WHOLE ROCK ISOCHRON

Sample number	Specimen type	Rb^{87} (p.p.m.)	Common Sr (p.p.m.)	$\frac{^{87}Sr^{Rad}}{^{87}Sr^{N}}$	$\frac{^{87}Rb}{^{86}Sr}$ (atomic ratio)	$\frac{^{87}Sr}{^{86}Sr}$ (atomic ratio) Spiked	Unspiked	Mean Sp & Unspiked
6243	K-feldspar	38.7	93.8	0.016	4.217	0.7161	0.7154	0.7157
6250	K-feldspar	82.3	37.7	0.087	22.297	0.7661	0.7652	0.7656
6259	K-feldspar	18.6	76.2	0.010	2.493	0.7106	0.7110	0.7108
6271 (AK-209)	K-feldspar	87.3	94.0	0.037	9.480	0.7303	...f..	0.7303
66-58A	Quartz monzonite	31.1	131.6	0.010	2.412	0.6987*	0.7109	0.7109
4011A-I	Quartz monzonite	27.2	199.0	0.004	1.394	0.7088	0.7070	0.7079

f failed run

* this value was not used for the isochron since it is definitely anomalous

an average of about 2 m.y. K-Ar dating on these relatively young rocks yields relatively small error in time duration which makes estimates of short time intervals feasible. If the mean K-Ar age of 198 $\pm$ 8 m.y. of 26 samples for the Guichon Batholith (Northcote, 1968) is compared with the Craigmont date, there is no difference. Any inference of a time interval between the emplacement of the batholith and the orebodies is doubtful because of the larger error limits. Future refinements in geochronological techniques might permit such distinctions.

The initial $^{87}Sr/^{86}Sr$ ratio from the isochron plot may indicate the type of source of the Craigmont mineralization. The general principles of this approach were outlined by Faure and Hurley (1963) and have been applied to ore deposits by Moorbath et al., (1967). A meaningful interpretation of the genesis must consider whether the batholith and ores were derived by melting at depth of relatively copper and iron rich crustal metamorphic rocks, or by differentiation from magmas derived from primary material below the crust. If the Guichon rocks and gangue minerals associated with the mineralization were derived from Cache Creek or Nicola rocks, in part derived from older rocks, the initial $^{87}Sr/^{86}Sr$ ratios should fall in the range 0.706-0.708 or higher (Peterman et al., 1967). The initial $^{87}Sr/^{86}Sr$ ratio for the Craigmont isochron is 0.704, which falls into the range of values (0.703-0.706) of recent basalts (Hedge, 1966). The writer concludes that the ore minerals and K-feldspar gangue did not originate by fusion

of ancient sialic basement or Cache Creek or Nicola rocks, but must have developed in an environment with low $^{87}Sr/^{86}Sr$ ratios similar to recent basalt. Such a source could be either the upper mantle, or a basic layer in the lower part of the crust or Nicola or Cache Creek basic volcanics. This interpretation is substantiated by sulfur isotope studies of sulfide minerals from the batholith and the Craigmont orebody. However, further strontium isotope studies are necessary to afford more conclusive results. Samples should be analyzed from the Nicola and Cache Creek volcanic and sedimentary country rocks to ascertain the initial $^{87}Sr/^{86}Sr$ ratios. The hypothesis of a deep seated source for the mineralization would be substantiated if a considerable difference between $^{87}Sr/^{86}Sr$ ratios for the country rocks and the K-feldspar gangue at the time of intrusion could be proved.

Sulfur Isotopes

Introduction.--Stable sulfur isotope variations in Craigmont sulfide minerals were studied to help interpret mineral genesis. Five pyrite and eight chalcopyrite mineral separates were analyzed for their S^{34}/S^{32} ratios. The various sample associations, descriptions and locations are outlined in Table 6.

Isotope ratio studies are a relatively new tool for interpretation of mineral genesis. The theoretical basis of sulfur isotope ratios for ore deposit studies is given by several authors such as Kulp et al., (1956), Jensen, (1959) and Stanton (1960). Their work indicated that

TABLE 6

SAMPLE DESCRIPTIONS AND ANALYTICAL DATA FOR SULFUR ISOTOPES

Sample Description		Mineral	S^{34} °/oo*
66-58A:	Quartz monzonite, Guichon Batholith: 121° 13' W, 50° 34' N; diss pyrite.	py	+2.9
4011A:	Quartz monzonite, Guichon Batholith; 120° 51' W, 50° 29' 30" N; diss py.	py	+1.9
6246A:	Hornblende diorite, underground; 10,315N, 9570E, 3666' elev.; diss py.	py	+0.5
6246B:	Quartz-sericite veinlet cutting 6246A; 10,315N, 9570E, 3666' elev.; diss py.	py	+0.2
6248:	Greywacke; open pit; 10,010N, 8400E, 3534' elev.; finely diss pyrite.	py	-6.8
6273:	Marble; 10,390N, 7470E, 3065' elev.; finely diss chalcopyrite.	chpy	-12.9
6243:	K-feldspar gangue; 10,300N, 9370E, 3600' elev.; massive diss blebs of chpy.	chpy	+0.4
6244:	Garnet epidote skarn; 10,330N, 9410E, 3666' elev.; finely diss chpy.	chpy	-0.2
6245:	Massive magnetite; 10,330N, 9400E, 3666' elev.; finely diss chpy.	chpy	-1.7
6249:	Massive specularite; 10,150N, 8370E, 3534' elev.; fine-grained chpy.	chpy	-3.0
6264:	Massive chalcopyrite; 2852' elev. 821 X-cut from high grade section of orebody.	chpy	-8.5
6265:	Massive platy magnetite; 2852' elev., 821 X-cut north; diss chpy.	chpy	-4.4
66-60:	Quartz diorite; chpy impregnation along minute fissure; 120° 11' W, 50° 40' N.	chpy	-2.0

*standard deviation based on reproducibility = ± 0.2 permil.

sulfur isotope ratios of sulfur bearing minerals often vary depending on source. Jensen (1967) elaborates this hypothesis and summarizes current thoughts on sulfur isotopes and mineral genesis.

Most studies deal with changes between the two most abundant isotopes, S^{32} and S^{34}. Variation in S^{34}/S^{32} ratios are usually expressed by δ S^{34} permil values as:

$$\delta\ S^{34}\ (^{o}/oo) = \frac{S^{34}/S^{32}\ \text{Sample} - S^{34}/S^{32}\ \text{Standard}}{S^{34}/S^{32}\ \text{Standard}} \times 1000$$

For the standard, sulfur from the troilite phase of the Cañon Diablo meteorite conventionally is used in which $S^{34}/S^{32} = 0.0450045$ (Ault and Jensen, 1962). Meteoritic sulfur therefore has the value $\delta\ S^{34} = 0$ permil. Samples enriched in S^{34} are isotopically heavy relative to the standard and have positive permil values; negative permil values indicate depletion of S^{34} relative to the standard.

A brief discussion of the sample preparation methods and isotope measurements is shown in Appendix C.

Results. In Table 6 analytical results from the study are outlined. The variance in results is graphically illustrated in Figure 9, according to five geologically distinct associations. Two pyrite samples from Guichon rocks believed to be primary sulfides formed contemporaneously with the enclosed batholith, have δ S^{34} values of +1.9 and +2.9 permil. These ratios are well within the range for igneous sulfur of possible upper mantle origin (Ault and Kulp, 1959; Thode, 1963). Disseminated pyrite samples from intrusive diorites collected underground at

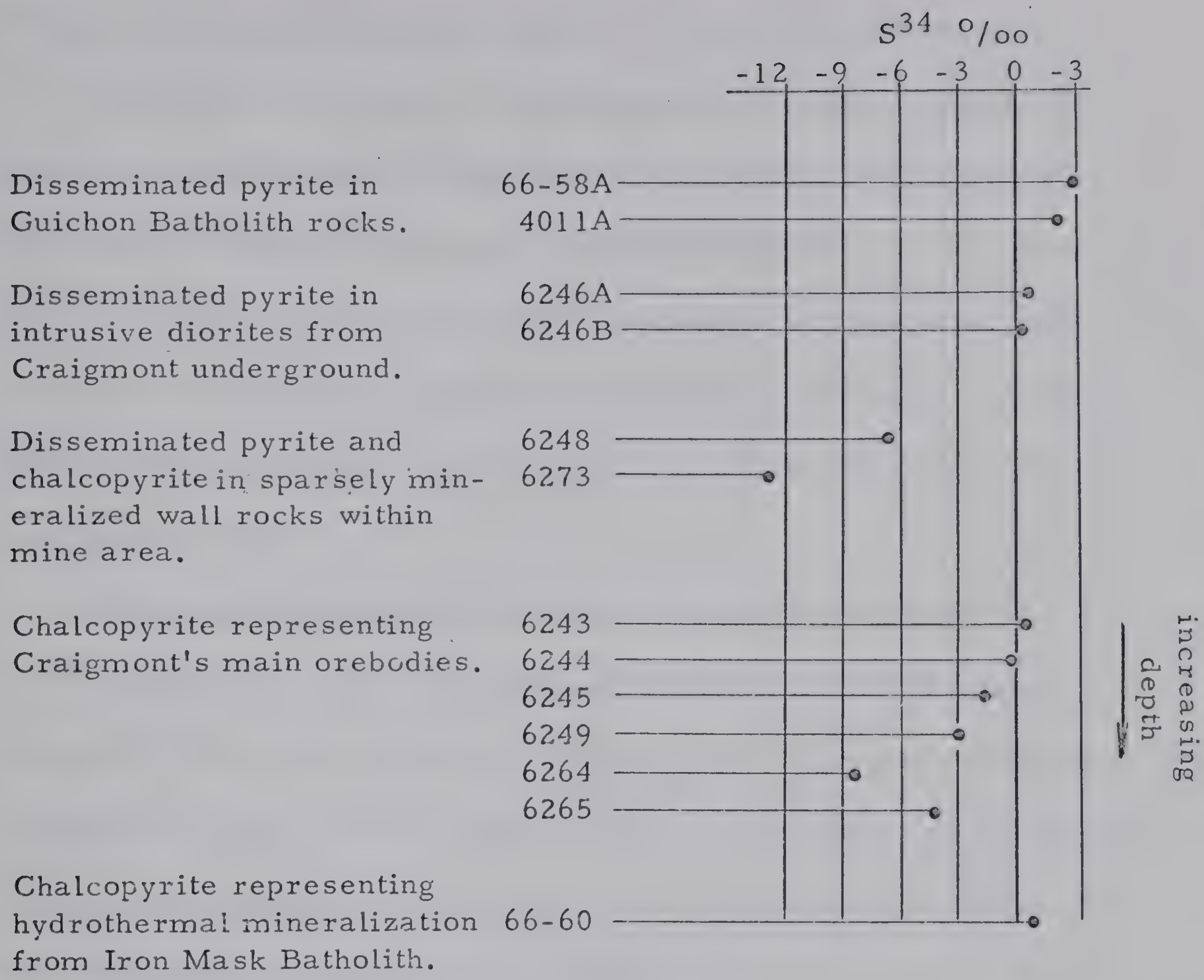


Figure 9. Sulfur isotope data showing variations for five geologically distinct associations.

Craigmont have similar values that are +0.2 and +0.5 permil.

In contrast two samples, disseminated pyrite from greywacke, and finely disseminated chalcopyrite in a recrystallized limestone, from sparsely mineralized wallrocks, have values of -6.8 and -12.9 permil respectively. These values (enriched in S^{32}) are often characteristic of sedimentary sulfides (Thode et al., 1949; Ault and Kulp, 1959) and may be considered representative of country rock sulfur in the Craigmont area.

Six samples of chalcopyrite from the main orebodies have δS^{34} values from +0.4 to -8.5 permil. Except for one specimen having δS^{34} of -8.5 permil, the data are relatively close to the value of meteoritic sulfur (zero permil). Significantly, almost all Cordilleran hydrothermal orebodies of magmatic association exhibit δS^{34} values near zero permil (Jensen, 1967). Examples are the porphyry copper deposits in Butte, Montana; Tintic district, Utah; Lark and United States mines, Utah; Central City, Colorado; and Marysvale, Utah (Field, 1966; Jensen, 1967). A chalcopyrite sample (#66-60) believed to represent hydrothermal copper mineralization from the Iron Mask Batholith northeast of Craigmont has a δS^{34} value of -2.0 permil which also fits into this category.

The δS^{34} value of -8.5 permil for sample #6264 is rather unusual for a product of primary igneous processes. Similarity between this value and those obtained from the wall rock sulfides appears to indicate that they have a common source of sulfur. If part

of the sulfur in the orebodies were derived from the country rocks this would explain the slight enrichment in S^{32} in most Craigmont ore samples compared to the primary igneous sulfides from the Guichon Batholith. The origin of massive sulfide deposits by introduction of country sulfur (sulfurization) has been summarized by Cheney (1967). Sulfurization processes at Craigmont may have been activated by high temperatures contributing to recrystallization of limestone, rock fracturing and skarn formation.

Data suggests two possible sources for the sulfur of this deposit--deep magmatic and adjacent country rocks. Some evidence indicates that sulfurization may have occurred only during the initial skarn formation and not during the second phase (veining phase) of mineralization. Supporting this hypothesis is the analysis of chalcopyrite from sample #6243 which gives a δS^{34} value of +0.4 permil close to meteoritic. This sample, representative of the second stage of mineralization, contains abundant K-feldspar gangue that was used for the Rb-Sr isochron and appears indicative of a deep-seated source.

The fairly wide range of δS^{34} values observed in samples from the main orebodies could have resulted from the mixing of magmatic sulfur and country rock sulfur in various proportions. The possibility exists that the sulfur isotope fractionation may have resulted from the sulfur-bearing minerals crystallizing from primary hydrothermal solutions without any introduction of country rock sulfur. However, the knowledge of isotope behaviour during ore forming processes is not

well understood and to date no conclusive evidence has been presented that fractionation equivalent to that found for Craigmont's main ore-bodies could result from direct crystallization.

The writer considers this sulfur isotope data a reconnaissance study and believes further investigations are warranted. Future studies should include further analysis of sulfur isotopic composition of country rocks adjacent to the orebodies. The two mineralization phases, skarn and vein, should be sampled to determine if there were two sources of sulfur operative at different times.

Oxygen and Carbon Isotopes

Introduction. Stable carbon and oxygen isotope ratios from Craigmont marbles and hydrothermal calcites were studied to help interpret processes of skarn formation and genesis of late calcite veinlets and calcite associated with the ore minerals. Twenty-eight samples analyzed for their carbon and oxygen ratios, are tabulated in Tables 7-10. Sample locations are given in Appendix D.

The first detailed application of oxygen and carbon isotopes to the study of hydrothermal ore deposits was made by Engel et al., (1958). Since then many studies utilizing oxygen for geothermometry estimations and some carbon data have been published. Recent workers, (Clayton, 1961; Garlick and Epstein, 1966; Rye, 1966; Taylor, 1967, and others) have applied oxygen and carbon isotopes to problems involving: (1) determination of temperatures of formation of

TABLE 7

ISOTOPIC COMPOSITION OF CARBON AND OXYGEN IN RECRYSTALLIZED LIMESTONE WITH GREATER THAN 5% SKARN MINERALS

Sample No.	Rock type	Comments	O^{18} PDB ($^{o}/oo$)	C^{13} PDB ($^{o}/oo$)
6255A	Marble	From main orezone, contains a variety of skarn minerals.	-18.0	+1.0
6273	Marble	Within 5 feet of known ore.	-18.8	+1.4
6276	Marble	From ore zone, this banded marble is highly altered with considerable quartz grains.	-17.1	+0.9
6280	Marble	Not a typical recrystallized limestone, contains fine grained calcite and rounded quartz grains.	-17.5	+1.8
6284	Marble	Slightly altered, contains numerous feldspar grains. Collected about 300 feet from mineralization.	-18.6	-0.5
6285	Marble	About 100 feet from mineralization, from stain around calcite crystals.	-16.4	+1.7
6286A	Marble	Breccia fragments containing twinned calcite, diopside and quartz.	-16.4	+2.1
6286B	Calcite	Calcite cement between breccia fragments of sample 6286A	-18.5	+0.2
6287	Marble	Sample taken within 5 feet of mineralization. Contains abundant skarn minerals, fine grained texture.	-18.5	+1.9
6288	Marble	Collected 60 feet from known mineralization.	-16.7	+4.0
6290	Marble	This altered marble contains about 20% skarn minerals and was collected adjacent to mineralization.	-20.4	+3.0
6291	Marble	Medium grained calcite with minor amounts of skarn minerals. Collected 10 feet from massive mineralization.	-20.7	-0.2
6293	Marble	Coarse calcite with 20% skarn minerals, 200 feet from mineralization.	-19.2	+0.1

TABLE 8

ISOTOPIC COMPOSITION OF CARBON AND OXYGEN IN HYDROTHERMAL CALCITE FROM CRAIGMONT, B.C.

Sample No.	Rock type	Comments	O^{18} PDB (°/oo)	C^{13} PDB (°/oo)
6258	Calcite	Calcite interstitial to chalcopyrite and quartz, from main orezone.	-20.6	-3.3
6264	Calcite	Calcite interstitial to massive chalcopyrite, from main orezone	-21.2	-3.8
6255	Calcite	White coarse euhedral crystals of calcite from main orezone.	-21.5	-2.9
6275	Calcite	White fine grained massive calcite distinctly different than recrystalized limestone.	-18.6	-4.4
6277	Calcite	Fine grained white calcite veinlet.	-20.5	-5.8
6278	Calcite	Fine grained white calcite veinlet.	-19.4	-3.5
6282	Calcite	Narrow calcite veinlet.	-23.5	-5.6
6295	Calcite	Weathered vuggy calcite veinlet.	-22.7	-12.8

TABLE 9

ISOTOPIC COMPOSITION OF CARBON AND OXYGEN IN RECRYSTALLIZED LIMESTONE WITH LESS THAN 5% SKARN MINERALS

Sample No.	Rock type	Comments	O^{18} PDB (°/oo)	C^{13} PDB (°/oo)
6272	Marble	Pure marble, trace amounts of skarn minerals.	-16.3	-0.6
6281	Marble	About 3% skarn minerals present.	-15.9	+1.5
6283	Marble	Less than 3% skarn minerals present.	-15.7	+0.8
6292	Marble	Partly recrystallized limestone.	-12.8	+2.3
6294	Marble	About 4% skarn minerals present.	-14.7	+3.1

TABLE 10

ISOTOPIC COMPOSITION OF CARBON AND OXYGEN IN LIMESTONE FROM NICOLA AND CACHE CREEK GROUPS

Sample No.	Rock type	Comments	O^{18} PDB (°/oo)	C^{13} PDB (°/oo)
6279	Ls Nicola Group	Impure black limestone with minor amounts of dolomite and carbonaceous material, slightly metamorphosed.	-20.4	+0.1
6274	Ls	Limestone from Cache Creek Group (Permian) west of Kamloops B.C.	-9.6	+3.3

oxygen-bearing minerals; (2) demonstration of equilibrium or non-equilibrium among oxygen-bearing minerals; and (3) information about the origin, nature and amount of hydrothermal fluids. The theoretical basis of such studies has been summarized by Taylor (1967).

Most studies report both oxygen and carbon results because little extra time is required to determine carbon after oxygen has been measured. The analytical results are usually expressed in terms of differences of O^{18}/O^{16} ratios and C^{13}/C^{12} ratios between samples and an arbitrary standard rather than the ratios themselves. The formula for determining the permil ($^{o}/oo$) difference for the sample from a primary standard is:

$$\delta = \left[\frac{R\ \text{sample}}{R\ \text{standard}} - 1\right] \times 1000$$

where $R = O^{18}/O^{16}$ or $R = C^{13}/C^{12}$ for samples and standard. Both the carbon and oxygen data presented refers to the PDB-Chicago (a fossil carbonate) standard. Use of a secondary standard for mass spectrometer analysis is discussed in Appendix D. The standard has values designated $\delta\ O^{18}$ and $\delta\ C^{13}$ = O permil. Samples enriched in O^{16} are isotopically light relative to the standard, whereas the reverse is true for samples enriched in C^{13}. A brief description of sample preparation and isotope measurement is in Appendix D.

Results. The carbon and oxygen analytical results are outlined in Tables 7 - 10, and graphically illustrated in Figure 10.

Recrystallized limestones or marbles that are host rocks for

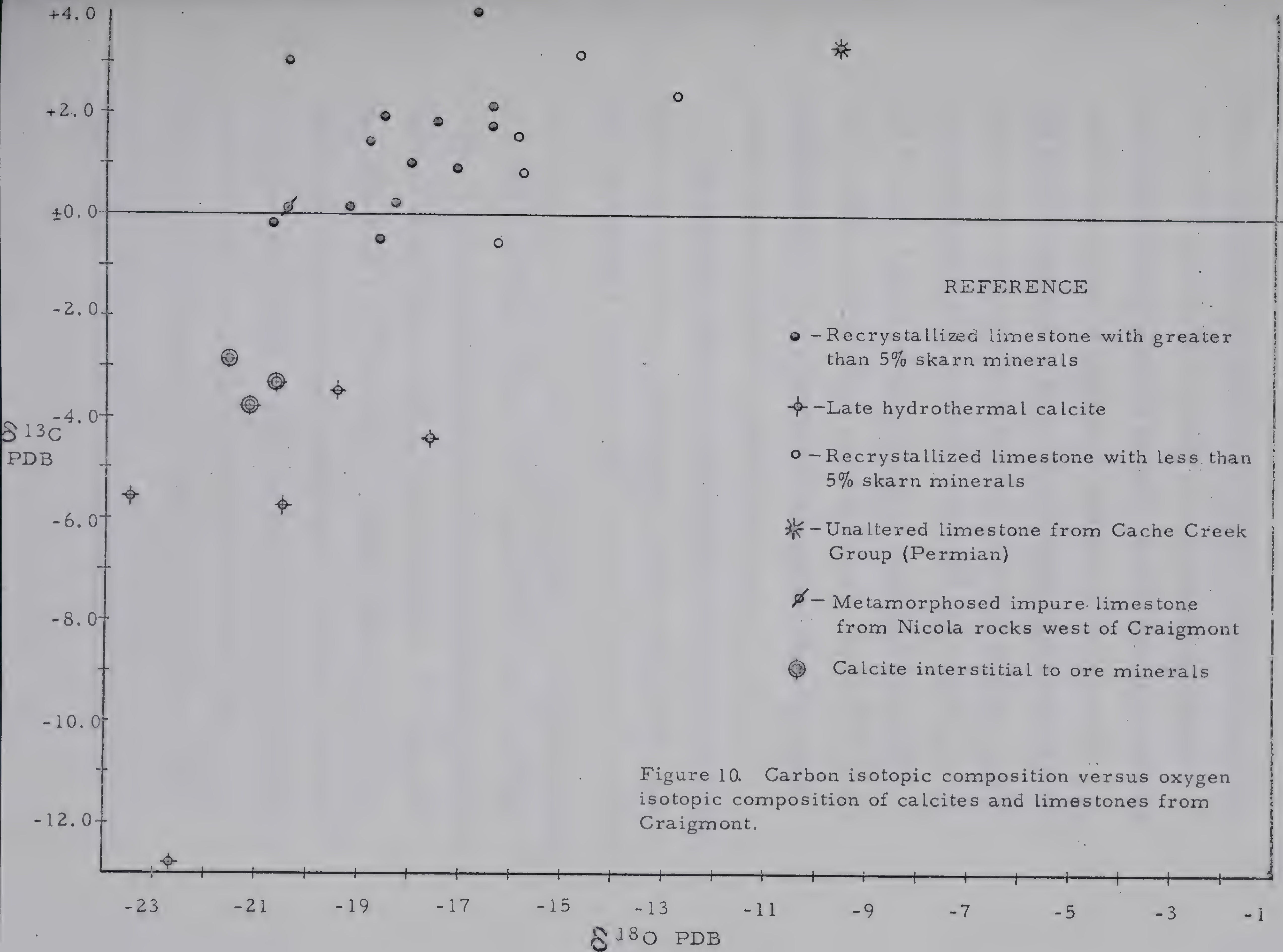


Figure 10. Carbon isotopic composition versus oxygen isotopic composition of calcites and limestones from Craigmont.

the Craigmont mineralization comprise the largest sample group. These marbles have been divided into two groups according to percentage of skarn minerals present. Mabble samples containing greater than 5 percent skarn minerals* are shown in Table 7. The $\delta\ O^{18}$ values range from -16.4 to -20.7 permil and the $\delta\ C^{13}$ values range from +4.0 to -0.5 permil. Marbles with less than 5 percent skarn minerals (Table 9) have $\delta\ O^{18}$ values ranging from -12.8 to -16.3 permil which are slightly more enriched in O^{18} than samples containing more skarn minerals. The $\delta\ C^{18}$ values range from +3.1 to -0.6 permil indicating little difference in the carbon isotopes between the two marble groups.

Impure black limestone from the Nicola Group collected approximately two miles west of Craigmont's open pit has a $\delta\ O^{18}$ value of -20.4 permil and $\delta\ C^{13}$ value of +0.1 permil. This impure limestone must have been altered as it is not representative of Triassic marine limestone according to isotopic values reported by Keith and Weber (1964). A limestone sample from the Cache Creek Group (Permian) collected about 30 miles north of Craigmont has a $\delta\ O^{18}$ value of -9.6 permil and $\delta\ C^{13}$ value of +3.3 permil. These values more closely represent the isotopic composition of "unaltered" Palaeozoic marine limestones found by Keith and Weber (1964). If Nicola rocks within the mine area originally had similar values then limestones became isotopically lighter in O^{18} due to recrystallization during

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*percentage of skarn minerals is estimated from thin sections

skarn formation. Two samples, (#6273 and #6287) collected within five feet of known mineralization, do not differ isotopically from samples collected several hundred feet from mineralization.

White coarsely crystalline late calcite that is associated with the second phase of mineralization and with massive chalcopyrite from the main orezones is isotopically distinct as shown in Table 8. For this group of samples the $\delta\ O^{18}$ values range from -18.6 to -23.5 permil and the $\delta\ C^{13}$ values range from -2.9 to -12.8 permil. These values indicate enrichment in the lighter isotopes for both oxygen and carbon. Sample #6295 which has a $\delta\ C^{13}$ value of -12.8 permil is anomalous and in hand specimen shows the effects of recent weathering. Three samples (#6257, #6264 and #6256) of calcite that were interstitial to ore minerals from the main orezone have an average $\delta\ C^{13}$ value of -3.3 permil.

Discussion of results. During contact metamorphism, Nicola rocks were recrystallized and disseminated skarn minerals formed along with chalcopyrite, magnetite and specularite. Elevated temperatures during this process initiated oxygen isotope fractionation between water and the CO_3 in the Craigmont limestones that resulted in lighter $\delta\ O^{18}$ values by approximately 8 permil in the analyzed marbles. It was found that analyzed specimens with higher skarn content, tend to have lower $\delta\ O^{18}$ values in agreement with their more pronounced metamorphism (higher temperature). In contrast

the $\delta\ C^{13}$ values of the marbles became isotopically lighter by about only 1 or 2 permil. Whereas the oxygen isotope fractionation implies elevated temperatures, the small change in $\delta\ C^{13}$ values indicates that deep-seated carbon was not abundant during skarn formation. This suggests that most of the CO_2 present, was formed from marine limestones whose original $\delta\ C^{13}$ composition was slightly above zero permil.

The $\delta\ O^{18}$ and $\delta\ C^{13}$ values distinguish the late calcite from the marble groups as indicated in Table 8. Significantly the $\delta\ C^{13}$ values for the late calcite are about 5 - 6 permil lighter than the marble group, whereas those for oxygen seem to have a tendency toward slightly lighter values. The average $\delta\ C^{13}$ value for the late calcite excluding sample #6295 which is weathered, is -4.2 permil. Using this value as reference, the isotopic composition of the carbon in the fluids which formed this young calcite is estimated to be about -4 to -6 permil. If no mixing of limestone carbon with magmatic carbon in the calcite occurred, then the $\delta\ C^{13}$ values could have been as low as -8 permil. These values fall in the upper range recorded for materials believed to represent magmatic or juvenile carbon. Rye (1966) estimated that the $\delta\ C^{13}$ values were -7 to -9 permil for carbon deposited by hydrothermal ore fluids derived from a magmatic source or cooling intrusion. The $\delta\ C^{13}$ values of carbonatite ejecta in Pleistocene tuffs from Germany, believed to represent primary igneous carbon derived from a gabbroic magma,

give a range of -6.6 to -8.4 permil (Taylor et al., 1965). The similarity between these values and those obtained for Craigmont substantiates a non-limestone source for a large portion of carbon in late calcite veinlets and for calcite interstitial to ore minerals.

Sulfur and rubidium-strontium isotopes together with the oxygen-carbon isotope data substantiate the hypothesis that the main ore forming fluids were derived either as a late-stage differentiate of the cooling batholith or as possibly juvenile water migrating from the mantle. The results indicate that the water involved during the ore forming processes had undergone high temperature exchange with resultant isotopic composition similar to juvenile fluids.

The carbon and oxygen data also possibly support the hypothesis that during the initial phase of mineralization (skarn formation), the orebodies may have formed partially by sulfurization. The δC^{13} values of marbles adjacent to the main orebodies support partial origin by sulfurization because δC^{13} values are similar to those from unaltered limestone. During the second phase of mineralization the carbon data of the late calcites infers that carbon in the form of CO_2 ascended from the mantle or a deep-seated source with small amounts if any during the skarn formation.

The writer believes further investigations of Craigmont oxygen and carbon isotopes are warranted. Future studies should include more detailed analysis of the oxygen and carbon isotopic composition of country rocks adjacent to the orebodies. A few samples from

unaltered country rocks should also be included. The possibility of utilizing these isotopes as a prospecting method might be investigated after local variations are more thoroughly understood. The writer suspects that more than one phase of calcite veinlets might exist. This would be essential information for future studies.

CHAPTER V

MINING AND METALLURGY

Mining

Introduction. Craigmont has used the most modern mining methods and mechanized equipment available since it began production in 1961. Near surface ore was exploited by open pit mining during Craigmont's first six years. On termination of open pit mining in March 1967, mill feed was supplied from massive stockpiles of open pit ore and from the remaining orebodies through a sub-level caving method.

During the development stage of Craigmont, feasibility studies were made of the relative advantages of open pit and underground mining methods. These studies, supported by field observations of open pit operations in the United States, indicated a combination of both methods with open pit operations from surface down to the 3500 foot level, followed by underground extraction of ore.

The most difficult problem for the engineers was to produce maximum profit from the mine during the first three years of operation (Hallbauer, 1962)*. Because of the variation in copper grade at Craigmont above 3500 feet elevation (and its effects on profits) a number of alternative schedules of mining were prepared. According to Hallbauer (1962) ..."a cash flow for the full life of the open pit was

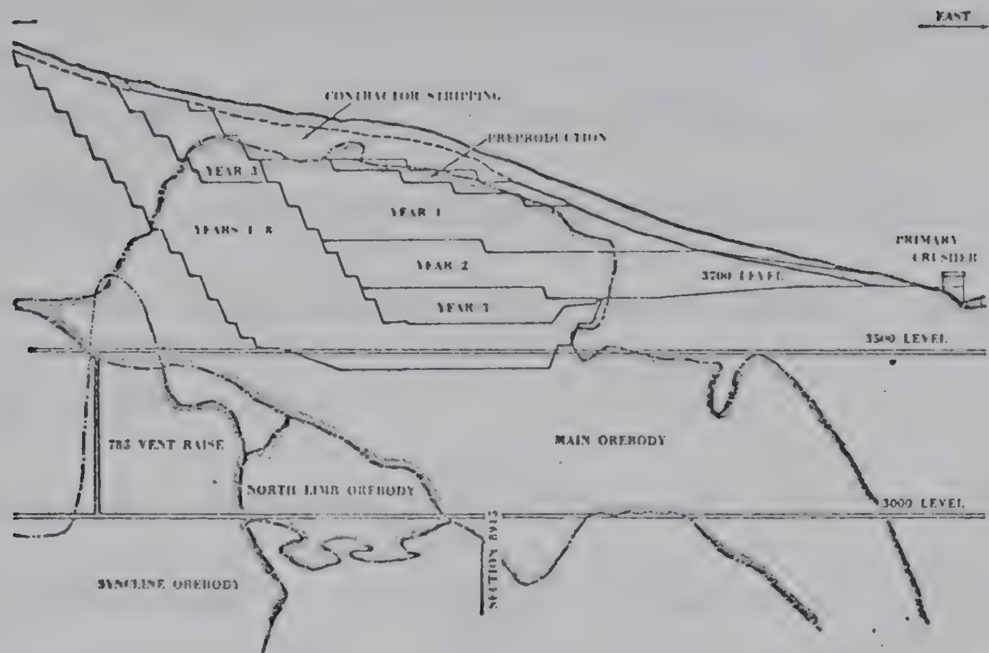
*According to federal tax law, corporations are allowed a three year tax exemption period on income derived from the operation of a mine beginning on the first production day.

prepared for each alternative. By using a variation of the Hoskold formula, the present value of the profit from each alternative was determined. By this means an overall open pit production schedule was planned." Figure 11 shows the plan adopted. The east end of the pit was to be mined and deepened first, then ore from the west end recovered.

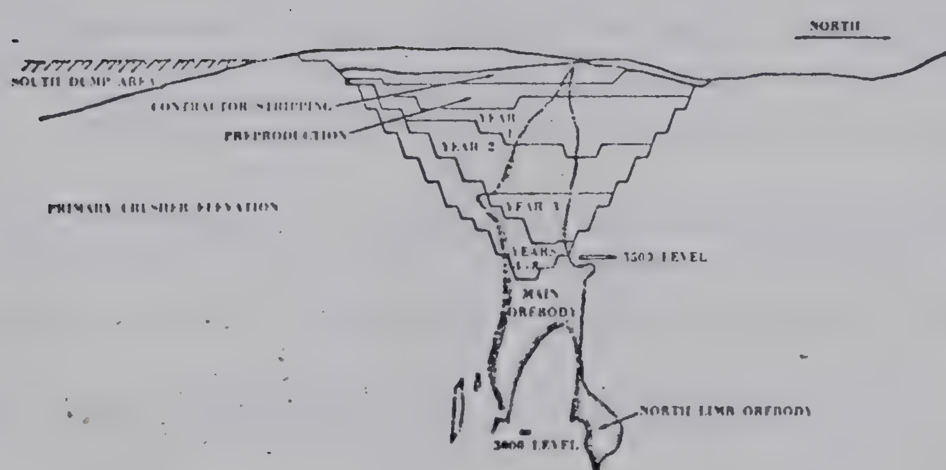
Open pit. The topography, nature of the orebody and ground conditions, made the Craigmont open pit unique in shape and operation. The pit, approximately 1500 feet across the original ground surface has an overall length of about 2000 feet in an east-west direction parallel to the orebody. The difference in elevation between the highest bench at the western end and the pit floor was about 1000 feet. Both the topography and the short length of the pit favoured the development of an external haul road system. Most haulage of ore and waste was downhill except for the last 225 feet in the pit from 3650 to 3425.

The main crusher installation which served the open pit, and currently is serving the stockpile, is at the 3700 foot elevation. From the primary crusher located adjacent to the eastern outlet of the pit, the ore is conveyed to the mill, at 2400 elevation, by means of a cable belt conveyor 5640 feet in length. When operating, the belt generates about 350 horsepower, enough to operate the primary crusher.

Initially the working benches were 33 feet high; and as mining proceeded two benches were consolidated to form a 66 foot bench. The overall wall slope of the pit was about 50 degrees, determined by



east-west section



north-south section

Figure 11. Sections showing Craigmont orebodies and the open pit mining plan used to obtain maximum earnings during the first three years of operation.

Yearly differences in grade of mill feed from using this mining plan:

Year 1 -------------- increased by -------------- 0.35% Cu
Year 2 -------------- increased by -------------- 0.52% Cu
Year 3 -------------- decreased by -------------- 0.39% Cu

Average for 3 years - increased by -------------- 0.18% Cu

(from Hallbauer, 1962).

having a 30 foot berm width on the benches with a slope of 70 degrees for each bench wall. The wall slope was subsequently decreased slightly when slow subsidence and surficial slumping, in the northeast corner of the pit began. As a result three million cubic yards of surficial material had to be removed from this corner, curtailing open pit production for a short time.

The waste to ore ratio for the material removed from the open pit averaged around 5.3 to 1. During its comparatively short life of six years the Craigmont pit produced an estimated 88 million tons of material including about 13.8 million tons of ore.

Electrically operated large-capacity shovels were used to load the broken rock. Three 4-$\frac{1}{2}$ yard shovels at Craigmont were capable of keeping a fleet of fourteen 27 ton diesel trucks hauling material to either the primary crusher, stock piles, or waste piles. The trucks were all equipped with automatic transmissions and torqmatic brakes. Planning the loading cycles and haul lengths for each truck was part of the daily duty of the open pit engineers.

After some experimenting with different types of drills, electrically-powered rotary drills were utilized for drilling most blast holes. Ammonium nitrate explosives, in slurry form mixed with fuel oil, is now standard in industry throughout. Together the implementation of ammonium nitrate-fuel oil mixture explosives and high performance drills have helped to keep down the cost of breaking rock.

Other small pieces of eqiupment such as bulldozers and road

graders were utilized for pit clean up. For equipment maintenance, and everything but major overhauls, a shop was built near the pit.

Even with the highly mechanized open pit mining about 80 men were needed to keep the operation running smoothly and efficiently.

Underground mining. At the same time open pit mining began, research was carried out to determine the most economical underground mining.method. To facilitate the choice of methods, test stopes were developed and mined. During the period 1961 -64, nine cut and fill, and two blast-hole stopes were in operation. These tests, supported by studies of other operating mines indicated sub-level block caving would be the most feasible and economic method of recovering the underground ore.

During the test period ore extracted from the stopes formed about 20% of the ore milled. Although this ore averaged only about 0.98% copper, the company was anxious to have the higher grade underground ore to provide flexibility in maintaining a uniform grade of mill feed.

According to Brissenden (1968) the increasing use of sub-level caving is one of the more important developments in underground mining in Canada. Since this method is applicable to special mining situations considerable detail is given in the following section.

This relatively old mining method which owes its resurgence to introduction of long-hole drilling equipment, improved blasting techniques, and trackless extraction units, (Cox, 1967), has

several advantages:

1. Selectivity in variable grade orebodies to provide uniform mill feed.
2. Adaptability to ore deposits of varying conditions such as width and inclination without affecting the mining plan.
3. Development work such as drifting is usually in ore rather than waste.
4. Permits easy standardization of equipment which results in lower costs.
5. Reduction of labour problems. (It is easier for mines to recruit personnel to operate mechanized equipment, where most of the hard work is taken out of the job, than it is to hire traditional miners).
6. Greater safety for miners because most of their work is in drifts.

At Craigmont it is estimated one half of future mining costs will arise from sub-level mining development (personal communication, E. W. Cokayne, chief engineer, Craigmont). Cox (1967) reported that development and mining costs are usually lower than those for blook caving or large sub-level open stoping.

A difficulty of this method is to obtain good recovery of the ore with little dilution from the unmineralized wall rock. Swedish mines that use sub-level caving have reported that their recovery ranges from 85-90% (Mamen, 1967). At Craigmont a recovery of 90% is

anticipated. The dilution factor, which is greatly dependent on the nature of the wall rocks, ranges from 10 - 40% in Sweden and is predicted to be about 20% at Craigmont.

To perfect sub-level caving at Craigmont, the application of this method at Kiruna, Sweden, the world's largest underground mine, was studied. A Swedish expert was employed by Craigmont to train local miners in the operating techniques of the special equipment used for this method.

The underground workings at Craigmont can be reached along three adits, 2400, 3060 and 3500 levels extending into the mountain from the eastern slope. The main haulage level is the 2400 which extends about 6000 feet to the western end of the orezone. The mine dry, mill and office buildings are also constructed at this level. Two shafts between the main levels provide access to the main orebodies. The shafts will soon be secondary to a system of inclines facilitating the movement of trackless equipment from level to level. On the 3432 sub-level a maintenance shop has been constructed for servicing the underground mining equipment.

To develop a block of ore for mining, parallel sub-level headings are driven at vertical intervals of 30 feet and horizontal intervals of about 25 feet. A section view of the development drifts seen in Figure 12, shows the typical checkerboard pattern of this mining method. The drift headings are 12 feet high and 11 feet wide. From these development drifts the engineers expect to recover about 12% of the

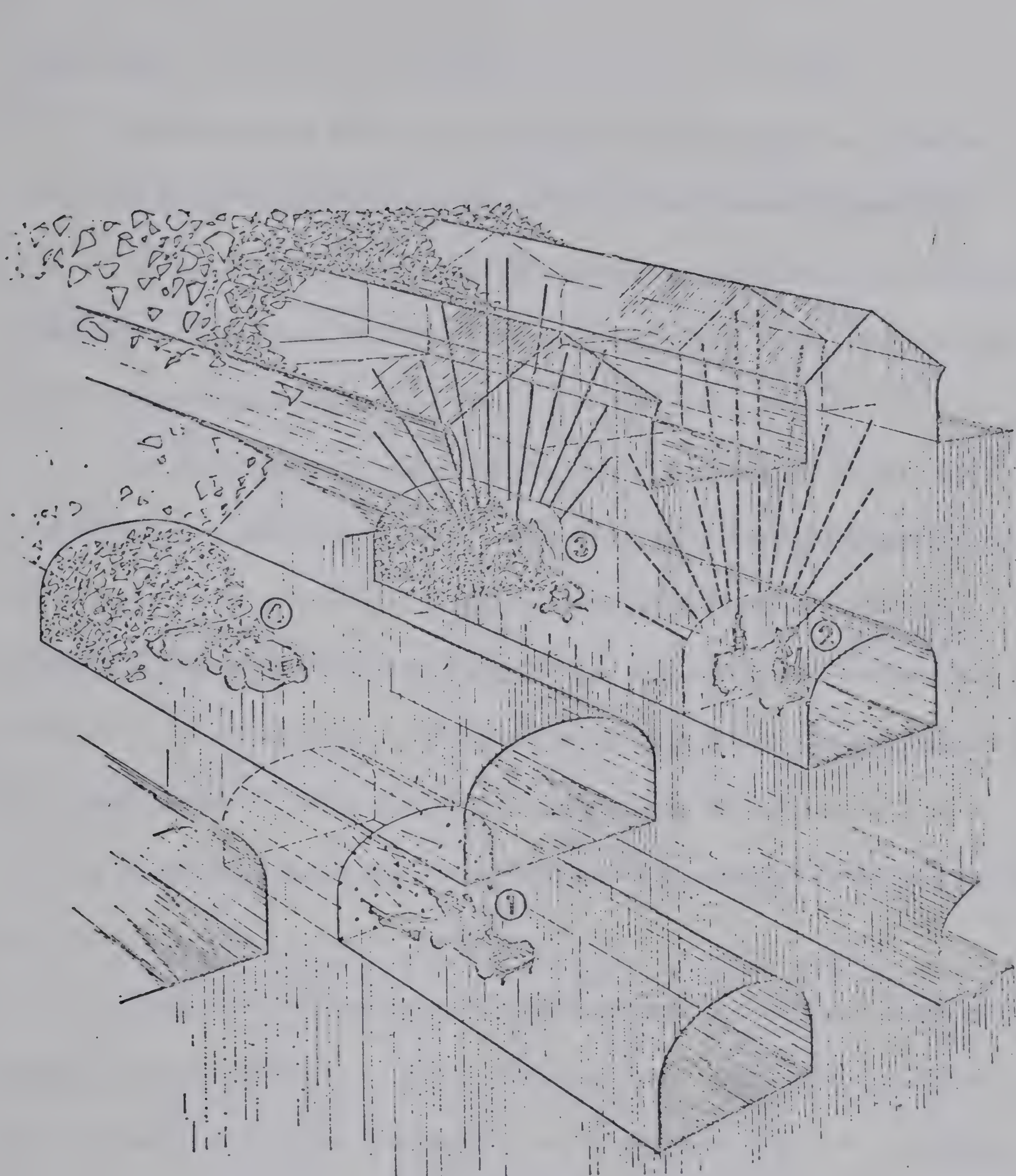


Figure 12. Diagrammatic plan of sub-level caving similar to method used at Craigmont: 1-drifting; 2-ring drilling (roof of slice); 3-charging of explosive; 4-ore loading (from Janelid and Kvapil, 1966).

total ore.

An interesting feature at Craigmont is the absence of timber and rock bolts in drifts even though the ground needs supporting. In place "shotcrete" is used to provide adequate support in development headings. The grout which is often applied up to 1" in thickness has little affect on mining and milling.

The development drifts are driven with three-boom Gardner Denver diesel powered jumbos. For drilling the long-holes in an overhead "ring" pattern, Craigmont has adopted the Atlas Copco Simba 26 pneumatic hydraulic rig. This one-man operated double armed rig has radically increased the footage drilled per manshift for blast holes. The ring drilling or fan-hole drilling in sub-level caving is carried out from the sub-levels with the holes drilled up to the next sub-level as seen in Figure 12.

Caving at Craigmont is proceeding from the western part of the upper orezone downward and toward the east. The cover of some 60 feet of waste rock that was backfilled in the open pit was to serve as a visual guide to the underground miners as well as provide a roof for containing the primary blasting. A number of large diesel Wagner Scoope-Tram loaders are used for transporting the broken ore to the ore-pass system. This vertical system, especially designed to handle large tonnages, extends from the main haulage levels to the upper levels. The chute is lined with special wear-resistant steel plates and has many gates for controlling ore flow. At the loading chutes closed circuit

television is mounted to monitor the remote control loading of ore trains.

Diamond drilling underground has been attempted on 50 foot centers to give adequate control for mining. All mine geology was originally plotted on vertical sections, but now for sub-level caving the geology is plotted in plan view. Mine geologists map approximately every third face of the development drifts for control. Since it is important to know whether the caved material is ore or waste in sub-level caving, the miners sample each muck pile. Considerable emphasis is placed on this sampling since the walls of the drifts are usually cemented as soon as the muck pile is cleared. The assay data from the muck samples are plotted on transparent overlays and used for mining control.

Transition period. The switch-over to wholly underground mining is still not complete (April, 1968). The extensive development necessary for sub-level caving such as inclined ramps and the parallel drifts has required more time than originally expected. As of February 1968, the underground mine was supplying 60% of the mill feed. The remainder was supplied from low grade stockpiles from the pit. Initial sub-level mining began to take the ore remnants around the walls of the open pit. These remnants, which are not continuous, occur in badly fractured ground which reduces mining efficiency. The staff has predicted that once mining proceeds to the main section of the orebody the "full effect of the highly mechanized mining method will be

experienced" (Craigmont Annual Report, 1967). The present result of the transition has been a significant decline in operating profits due to lower grade of ore milled.

Milling

The milling procedure at Craigmont has been documented in detail by Wright (1963) whose paper includes a flowsheet of the Craigmont plant. No major mill changes have been made since then with the exception of an addition to the concentrator regrind section in 1964 to improve the concentrate grade and mill throughout. During the last two years the Craigmont concentrator has been milling about 5500 tons per 24 hour day.

The nature of the copper at Craigmont makes the metallurgy relatively simple. Chalcopyrite is the only significant economic mineral. The two forms of chalcopyrite, massive and disseminated, significantly influence the recovery and grade of concentrate obtained. When the finely disseminated ore is milled, a lower grade concentrate results. The variation in concentrate grade lies between 29% copper for typical high grade ore, and 24% copper for typical disseminated ore (Wright, 1963). The grinding capacity of the mill is influenced by the relative hardness between magnetite and soft specularite. Content of these minerals vary widely in the ore thus providing wide fluctuations in the grinding.

Other than minor compensations for variations in the character of the ore, the procedure for milling the Craigmont ore is standard. A

series of three crushers breaks the broken ore down to grinding size. A series of conveyors carry the ore to storage bins and eventually to two parallel circuits each consisting of a rod and ball mill for grinding the feed for flotation, thickening and filtration. Recovery of the copper in the mill circuit has been somewhat variable in the past primarily due to the variable grade of the oxidized ore from the upper benches in the open pit. When grade of mill feed is regular then a maximum recovery of around 97% is obtained.

Water is often in short supply in the dry Merritt area, therefore some 55-60% of the water used in the mill is recovered from the tailings thickners. Just below the mill plant a large tailings dam and reservoir has been constructed. In the future if more economical transportation is developed, or if the price of iron increases, probably an attempt will be made to recover the iron which is impounded in the tailings at Craigmont.

The final copper concentrate is trucked about five miles to a rail siding at Coyle, near Merritt, and is shipped in covered gondola cars to Vancouver and then by ocean freighter to Japan.

CHAPTER VI

EVALUATION OF CRAIGMONT

Introduction

The present value of the Craigmont orebody, which is reflected more or less accurately in the market value of the common shares, embraces the interrelation of ore reserves and profits, and then is subjected to the variables of wages, efficiency of mining method adapted, cost of materials and the fluctuating price of copper in world markets. Most of the following data is based on statistical information made public by Craigmont up to the 1967 fiscal year ending October 31.

Ore Reserves

Ore reserves with no allowance for dilution are tabulated in Table 11. For comparison the estimated ore reserves for 1960 immediately before Craigmont began production are included. Recent reserve estimates no longer include iron content of material mined, which in 1960 averaged about 19% iron per ton.

Ore reserve calculations at Craigmont were based on an assay boundary of 0.35% copper for the open pit and 0.70% copper for underground ore. Cost accounting during initial open pit mining and underground testing helped determine these cut-off grades. Use of the assay boundary requires detailed sampling control because of irregular copper values near the orezone periphery, where chalcopyrite is widely disseminated.

Geologic sections with copper assay overlays prepared by

TABLE 11

SUMMARY OF CRAIGMONT'S ESTIMATED ORE RESERVES FOR 1967 AND 1960*

1967 Ore Reserves	Tons	% Copper	
Broken stockpiles	4,358,333	0.56	
In place, semi-proven underground	16,369,279	2.03	
Total	20,727,612	1.72	
1960 Ore Reserves			
Main orebody above 3500, open pit	8,635,000	1.82	increasing depth
Main and northern orebodies below 3500	6,897,000	2.15	
Syncline orebody	7,043,000	2.34	
Total	22,575,000	2.08	
Additional low grade adjacent to ore bodies	5,179,000	0.52	

*(From Craigmont annual reports).

Drummond (1966) show that there is considerable marginal protore adjacent to the principle zones. This protore ranges in grade from less than 0.1% copper to 0.7% copper. Some dilution of the ore will be unavoidable by inclusion of submarginal grade material in mining with correspondingly slight increase in tonnage treated. Table 11 shows that the protore was estimated at about 5 million tons of 0.5% copper in 1960 and possibly could have increased since then.

Since assay boundaries are used to determine ore reserves at Craigmont, fluctuations can be expected in the total amount of ore reserves from cut-off grade changes. For instance, when the cut-off grades were lowered during the 1961-62 period, a substantial increase in ore reserves resulted as seen on Table 12. Craigmont cut-off grade has remained unchanged since then.

The main factors that could affect any future changes in the cut-off limit are changes in the price for copper and in mining costs.

The price Craigmont has received for its contained copper has shown a wide range from 1962 to 1967 as seen in Table 13, however, this variance did not cause the company to alter its cut-off limits to make more mineralized rock available as ore. A more radical upward trend in copper price appears necessary for this to be undertaken. The economics of copper and its future supply and demand are discussed briefly in a later section.

The cost of sub-level caving seems a more important variable than copper prices because the success of this method will have a long

TABLE 12

YEARLY CHANGES IN ESTIMATED ORE RESERVES, AMOUNT OF ORE RESERVES REMAINING, AND ANNUAL MILL PRODUCTION

	Estimated increase ORE RESERVES		PRODUCTION		Estimated total ORE RESERVES	
	Tonnage	% Cu	Tons Milled	% Cu	Tonnage	% Cu
1961	....	....	222,133	1.43	22,575,000	2.08
1962	+4,140,005	0.96	1,797,005	2.10	25,918,000	1.82
1963	+649,215	0.86	1,765,215	1.83	24,792,000	1.75
1964	+253,321	1.78	1,874,321	1.63	23,171,000	1.76
1965	-634,934	0.65	1,616,615	1.16	20,919,450	1.84
1966	+1,288,418	0.29	989,144	1.54	21,218,724	1.76
1967	+1,519,120	1.15	2,010,232	1.71	20,727,612	1.72

TABLE 13

SUMMARY OF OPERATING STATISTICS, CRAIGMONT*

	1967	1966	1965	1964	1963	1962
Tons ore milled	2,010,232	989,144	1,616,615	1,874,321	1,765,215	1,797,005
Calendar days	365	192	335	366	365	365
Average tons milled per day	5510	5150	4828	5121	4836	4710
Average grade - mill feed- % copper	1.71	1.54	1.16	1.63	1.83	2.10
Percent recovery	96.7	94.5	94.2	93.6	95.8	97.0
Concentrate produced -short dry tons	118,263	53,312	63,927	97,333	111,862	125,001
Average concentrate grade - % copper	28.12	26.98	27.59	29.47	27.70	29.43
Market value of production - dollars	29,437,309	14,680,001	11,829,663	17,003,896e	17,618,511e	20,924,897e
Total production** costs - dollars	18,803,746	7,473,578	9,588,879	11,822,328e	11,032,917e	10,187,408e
Total production ** costs per lb copper	28.3¢	26.0¢	27.2¢	20.6¢	17.8¢	13.8¢
Price copper (U.S. export)	44.2¢	52.1¢	35.8¢	29.6¢	28.4¢	28.4¢
Net profit - dollars	11,166,497	7,267,627	2,256,248	5,181,568	6,585,594	10,737,489
Net profit per lb copper	16.8¢	25.3¢	6.4¢	9.0¢	10.6¢	14.6¢
Net profit per share - dollars	2.20	1.43	0.44	1.02	1.30	2.11

* - fiscal years ended October 31

** - this value includes expenses such as income tax, depletion and depreciation.

(e) - estimate

term influence on profits with possible subsequent changes in cut-off grades and thus ore reserve determinations. Although underground mining will be considerably more expensive than open pit mining it could be compensated for by increasing ore grade with depth. On Table 11 the increasing grade with depth is shown. Nearly all known ore is above the 2400 main haulage level so costs should not increase with depth.

Increasing total recoverable ore through new discoveries has the greatest potential. McKinstry (1948) summarizes its importance ..."the outlook for ore beyond known reserves has a value which cannot be ignored, even though its magnitude is a matter of geological judgment and its existence involves a sizable element of risk."

In Table 12, yearly increases in ore reserves are documented. Each year since 1961, except 1965, new ore was found by closely spaced diamond drilling to aid mining. Until recently 95% of all exploration was above the 2400 foot elevation since new ore from this zone could be mined by the present major development. Below the 2400 elevation the ultimate depth of the ore has not been completely ascertained and exploration in this direction may yield new ore. Craigmont has done a little, though unsuccessful, exploration west of the main orebodies. According to Keevil (1965) this direction offers the greater probability of finding a comparative skarn type ore deposit, ranging between 3-7 million tons, than any other direction. A serious drawback for exploration in this direction is the thick capping of

Kingsvale rocks. The Nicola rocks in this area seem to be down-faulted along a major NW-SE fault which further complicates exploration. Because drilling is expensive and difficult through the Kingsvale rocks Craigmont may eventually explore this area by drifting. This costly method however, may not be justified because the estimated expenditure might nearly equal the expected value of ore (Keevil, 1965).

Summary of Ore Reserve Estimates

If copper prices remain around 40-50 cents per pound (E&MJ export price) and production costs remain constant, then Craigmont's reserves may range between 21 million tons of 1.72% copper (reserves reported in Craigmont Annual Report, 1967) and about 31 million tons of 1.5% copper. The latter estimate to aid maximum present value calculations, include 5 million tons to be found during exploration within the present mine area. This assumption is based on past yearly reportings by Craigmont of reserve additions. Another 5 million tons are also added to the reported reserves assuming extra dilution by sub-marginal ore. The following summarizes the reported ore reserves and estimated maximum reserves:

MINIMUM ORE RESERVES as of November 1, 1967:
(reported by Craigmont)
= 20,700,000 tons grading 1.72% copper

MAXIMUM ESTIMATED ORE RESERVES as of November 1, 1967:
= 30,700,000

Recoverable copper. Craigmont's present reserves fit into two major groups--broken stockpiled ore, and in-place underground ore. The stockpiled ore should all be milled with no loss, whereas approximately 10% of the underground ore will likely be lost during mining. This 10% loss or 90% recovery estimated for sub-level cave mining at Craigmont is not an established value as the mining method is not really in full operation, but the 90% recovery is similar to the recovery obtained in operating mines using this method.

Dilution of ore with protore or waste rock may be a major problem with the sub-level cave mining method at Craigmont. Dilution in mines with favourable mining conditions is at least 10% whereas 20% dilution was estimated for Craigmont. The high dilution at Craigmont is due to the nature of the sub-level cave mining method and the characteristics of the rock. The ore is extremely hard in contrast to the surrounding skarn rocks that are heavily fractured and slough considerably after blasting.

Dilution, unfortunately, results in added tonnage of material of less than the estimated cut-off grade. Since along with the ore dilutant rock is shipped to the mill, an estimation of its grade should be made in order to predict the tons and grade of copper Craigmont will produce in the future. The dilutant rock grade can be established by comparing the sampled grade with the millhead grade. Craigmont has not published the grade of the dilutant wall rocks so a conservative estimate of 0.3% copper is considered based on interpretation of geologic

sections from Drummond (1966) showing assay values adjacent to the orebodies.

The third aspect at Craigmont that affects the copper recovery is the milling process. The copper recovery for the mill is reported annually. For the first six years, it ranged from 93.6 to 97.0% with an average of 95.3%. A great many factors affect mill recovery and although the metallurgists continually attempt to achieve better recovery, they are often hampered by rapid changes in the character and grade of the mill feed. When the effects of mine recovery, mine dilution and mill recovery are taken into account the actual tonnage produced will be slightly greater but the grade will be lower than the estimated ore reserves. The changes in ore reserves due to dilution and mine and mill recovery are shown in Table 14.

Estimated life. In order to estimate the remaining years in Craigmont's life some value for the rate of production of the mining and milling must be determined. For this study the milling rate rather than the mining rate governs the life of the mine.

During the last two years, 1966 and 1967, milling has been at an average of 5530 tons per day. Based on the maximum and minimum recoverable ore reserves at the production rate of 5530 tons per day, Craigmont's life expectancy is between 11 and 17 years. Many factors such as strikes, equipment breakdown, labour shortage, weak copper market, readjustment in mining methods or management changes

TABLE 14

MAXIMUM AND MINIMUM CHANGES IN ORE RESERVES AFTER CONSIDERATION OF DILUTION AND MINE AND MILL RECOVERY

	MINIMUM*			MAXIMUM**		
Stockpiled Open Pit Ore						
Recovery	100%			100%		
Dilution	negligible			negligible		
Total tonnage and copper grade		4,400,000	0.56		4,400,000	0.56
Underground Ore						
Recovery	90 %			90 %		
Dilution	20 %			20 %		
Estimated grade in wall rocks	0.3%			0.3%		
Estimated recoverable ore	(16,300,000 x90%) =	14,700,000	2.03	(26,300,000 x 90%) =	23,700,000	1.66
Estimated tonnage from wall rock dilution	(14,700,000 x20%) =	3,000,000	0.3	(23,700,000 x 20%) =	4,700,000	0.3
Total tonnage and grade		22,000,000	1.51		32,800,000	1.31
Milling						
Average recovery since 1961	95.3%			95.3%		
Total estimated tons of recoverable copper	(22,000,000 x1.51% x 95.3%) =	317,000		(32,800,000 x1.31% x 95.3%) =	410,000	
Total estimated pounds of recoverable copper	(317,000 x 2000) =	634,000,000		(410,000 x 2000) =	820,000,000	

*Reserves estimated by Craigmont as of November 1, 1967.
**Using an additional 10 million tons above 1967 ore reserves.

may potentially alter a mine's life. If additions are made to the plant or if research can establish methods of higher milling rates, then the life of the mine may be overestimated. Although Craigmont's life depends mainly on its ore reserves and milling rates, consideration must be made for other unpredictable factors, that may change the life span.

PRODUCTION ESTIMATE:

5330 tons per day x 365 days = 1,900,000 tons per year

MINIMUM LIFE OF CRAIGMONT

$$\frac{22,000,000 \text{ tons recoverable}}{1,900,000 \text{ tons per year}} = \ldots\ldots\ldots\ldots\ 11 \text{ years}$$

MAXIMUM LIFE OF CRAIGMONT

$$\frac{32,800,000 \text{ tons recoverable}}{1,900,000 \text{ tons per year}} = \ldots\ldots\ldots\ldots\ 17 \text{ years}$$

Mineral Economics

Copper. Craigmont's life and profits are intimately related to future copper prices and world copper markets which are difficult to predict because of many complex political, social and economic factors.

Six countries supply most of the world's copper. In order of decreasing production they are: United States, U.S.S.R., Chile, Zambia, Canada and Congo. Of these countries, Chile, Zambia, Canada, Congo, and in addition, Peru, supply more than 70% of the exportable world copper. The United States is a major importer of copper along with western Europe and to a lesser extent, Japan.

Canada exports 50-70% of its total copper production. Of this

about half goes to the United States; the remainder going primarily to the United Kingdom. British Columbia copper mines which do not have access to a Canadian smelter, export their copper concentrates to Japan.

Canadian companies marketing their copper products in Canada receive the Canadian producer's domestic price, similar to the United States producer's domestic price. These prices which are relatively stable vary only under extreme market pressures. In contrast, Craigmont's sales are based on the Engineering and Mining Journal (E&MJ) export copper price. The E&MJ export price is determined on the average of reported sales by most world producers outside the United States. Other world prices for copper, such as that set by the London Metal Exchange, illustrate the conflicting interests that countries have. For example, countries which derive major revenue from their copper industries try to maintain high copper prices. In contrast, the United States until recently has been enforcing a low price for copper set at 38 cents per pound to help restrain inflation. The United States is able to enforce a low domestic price by placing embargos on copper exports, releasing copper from strategic stockpiles and by allocating copper for defence purposes.

The range of copper prices during the last 7 years shows why accurate predictions regarding future copper prices and markets are difficult. Unpredictable events such as the Vietnam war have created an increased demand for copper. The Middle East crises also resulted in minor fluctuations in the prices. Beginning on July 15, 1967, the

world copper markets were significantly affected by a strike of copper company workers in the United States which crippled about 90% of the country's production capacity. The strike finally ended for most companies in late March 1968--a duration of nearly $8\frac{1}{2}$ months.

The tight markets resulting from the strike meant better selling prices for Canadian producers and since copper is Canada's leading metal in terms of value,(280 million dollars in 1967) the higher prices helped the national economy as well as that of individual mines which export. When settlement of the strike was announced, the London Metal Exchange copper prices rapidly declined. Copper prices also decreased slightly when peace talks between the United States and Vietnam were announced in early April, 1968.

Many mineral economists expect that copper supplies will continue "tight" for some months after settlement of the U.S. strike. This has not proven completely true, however, because many producers still hold excessive inventories. But what about copper prices 5 to 10 years from now? To answer this question the world reserves and future demands for copper must be considered. Estimation of world copper reserves is hampered by the tendency of major companies to be either conservative or secretive, or both. World copper reserves are wasting assets, so in order to meet demands, the mined tonnage must increase correspondingly. Table 15 shows that mineral content of mined copper ore has decreased considerably over the last 60 years. This decrease partially reflects the introduction of mechanized open pit mining.

TABLE 15

GRADE OF COPPER ORE MINED IN THE UNITED STATES 1880-1956
(from Netschert and Landsberg, 1961)

1880 - 3.0%	1906-10 - 2.1%	1931-40 - 1.6%
1889 - 3.3	1911-20 - 1.7	1941-50 - 1.0
1902 - 2.7	1921-30 - 1.6	1951-56 - 0.8

An attempt to illustrate the world supply or reserves of copper in relation to estimated cumulative demands through the end of the century is shown in Figure 13. The following data is based on the work of Netschert and Landsberg (1961). Two types of reserves, measured and inferred, are used to arrive at present world reserves. The curve, in Figure 13, representing reserves, continues indefinitely along the quantity scale as a recognition that there exists an undiscovered amount of ore meeting present criteria for reserves. The curve representing the identified potential ore down to 0.5 percent average copper slopes gradually upward to signify that higher costs can be expected with lower grade copper ores with increasing time.

Quantities A and B in Figure 13 represent cumulative world demands up to year 2000 at two different assumed growth rates. Quantity B, 551 million tons, is the result of a growth rate of 5.0% based on the rate between 1950 and 1960. Quantity A, 423 million tons, is the result of a 3.9% rate that world consumption experienced between 1955-1960. If

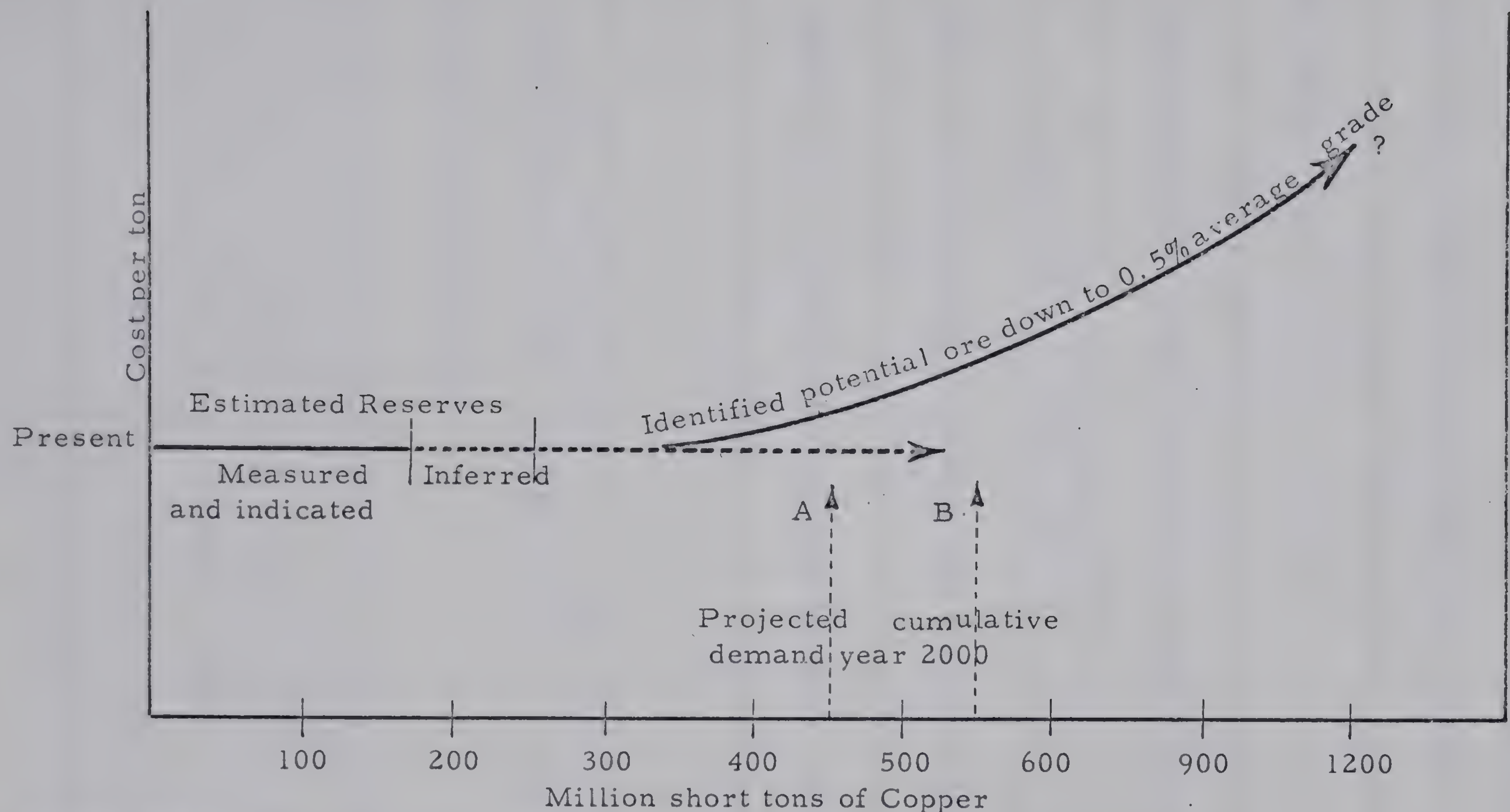


Figure 13. Adequacy and cost implications of projected world demand for copper.
(From Netschert and Landsberg, 1961)

these rates hold true until the years 2000 then it is obvious that additions to present reserves and recovery of lower grade copper ores must be made. An interesting feature of copper mining resulting from technnological advances is that the cost of mining copper has not risen proportionally to decreases in copper grade as shown on Table 15 (Netschert and Landsberg, 1961).

Copper, an international commodity, is essential for industrial development. Free world consumption has grown about 6% annually since World War II and is likely to continue at 4 to 5% in the future. Copper prices have followed a similar trend and risen with consumption and inflation. Some mineral economists predict that during the early 1970's production will exceed consumption for a short time with subsequent lower copper prices. This decline will most likely be the result of foreign countries substituting other metals, such as aluminum, for copper.

If the growth rate of copper consumption averages about 5% in the future then possibly Craigmont is assured of average prices and a strong market for sales during its remaining life.

Iron. Assuming an average grade of 20% iron, a minimum of 6 million tons of iron exists in the Craigmont orebody and tailings pond. Considerable research on iron recovery by Craigmont shows it is technically feasible to produce a specularite-magnetite concentrate, but transportation costs are a deterring factor for profitable marketing

of the iron. The magnetite and specularite currently mined with the chalcopyrite are impounded in the tailings pond with waste rock so that if reductions in transportation costs or price increases occur, these minerals could be easily exploited.

At present, world iron ore production facilities are abundant and competition for existing markets has driven the price of iron ore to low levels. Recently negotiated contracts between British Columbia producers and Japanese consumers call for slightly lower prices than British Columbia mines received in 1966. These prices ranged from $8.75 to $9.25 for magnetite concentrates containing about 62% iron f.o.b. metric tons (Gauvin and Schneider, 1967).

Estimated costs for shipping iron ore from the Merritt area to Vancouver are based on the published rates by Dubnie (1962). Such data roughly illustrates why transportation costs are such a deterrent factor. In 1960 the average cost of shipping concentrates by rail within Canada was about 1.3 cents per ton mile. Craigmont is about 200 miles from Vancouver so minimum costs for rail transport including handling charges would be about $3.00 per ton. Since most iron prices are for f.o.b. at the western Canadian ports such as Vancouver, then oceanic transportation costs to Japanese ports need not be considered. Loading at dockside which would add a minimum of $1.50 to $2.00 dollars so that the minimum total transportation costs from Merritt would have been nearly $5.00 per gross ton in 1960. To this value now must be added production costs, thus the reason why iron recovery is uneconomical at present.

In the future a price rise for iron ore is unlikely because of active competition of countries such as Australia, Brazil, Chile, India and Liberia where extensive reserves of high-grade direct shipping ore are available for year round open pit mining.

Craigmont might benefit from reduced rail rates due to an increase in shipped tonnage from interior British Columbia to Vancouver by bulk trains. This increased tonnage will come from new mines going into production such as Brenda, Lornex, and possibly Copper Mountain and Highmount. The construction of bulk loading facilities for the new "super-freighters" (100 thousand tons) should result in lower loading costs. Whether Craigmont can take advantage of these developments in transportation is speculative.

Toward the end of Craigmont's life when lower transportation rates might be in effect and most of the iron in the tailings, recovery of iron in a massive operation probably would be most economical.

Smelter possibilities. Another development which could have a favourable effect on Craigmont's future income would be the construction of a smelter in south central British Columbia. To encourage this construction the B. C. government established a one cent per pound copper bounty for copper refined within the province. Even the present copper production in British Columbia is more than enough to keep a smelter operating at an annual capacity of about 700,000 tons. Cheap electrical power and the main oil and gas pipe line traversing

the copper rich area also favour construction of a smelter. A copper smelter for the interior appears inevitable if other copper prospects such as Lornex, Copper Mountain and Highmount plan production as Brenda Mines is doing. As far as Craigmont is concerned a smelter in British Columbia might be constructed too late in its life to provide any real increase in profits. At the time of writing (May 1968) no immediate plans for construction of a smelter have been announced.

Estimate of Gross Revenue

The gross revenue available from production at Craigmont depends mainly on: (a) tonnage of copper recoverable from mining and treatment of the ore potential, and (b) price received per pound of copper when sold on the world market.

Estimates of recoverable copper based on proven and probable ore anticipated from mining and further development progress, vary from a minimum of 634,000,000 pounds copper to a maximum of 820,000,000 pounds. As the milling rate is assumed constant, life of the mine, accepting the above extremes, will vary from 11 years minimum to 17 years maximum.

During life of the mine, world copper price is a variable. In these calculations it is assumed that the minimum price received for copper will be 40 cents and the maximum 50 cents. Considering the normal increase in consumption due to an expanding economy in western nations, and progress in underdeveloped countries, plus

steadily increasing pressure of wage demands and lastly world reserves of copper, it is probably the average price received will be at least 40 cents per pound.

Using the above figures the gross incomes are indicated as follows:

634,000,000 lbs Cu --	@ 40¢ =	\$254,000,000
	@ 50¢ =	\$317,000,000
820,000,000 lbs Cu --	@ 40¢ =	\$328,000,000
	@ 50¢ =	\$410,000,000

Production costs. Total annual production costs and corresponding cost per pound of copper produced are listed in Table 13 for the years 1962-1967. The cost per pound of copper produced has increased from a low of 13.8 cents in the early years to 28.3 cents in 1967. This cost increase is due to initial payments of income tax, higher wages and salaries paid and higher equipment operating costs which have been increasing at a rate of between 5 and 8% per year.

In estimating future costs per pound of copper produced, there is an interplay between improved operating conditions, costs in plant operation, increase in wages, replacement parts and possibly tax increases. For these calculations it is assumed this increment in cost will average between $3\frac{1}{2}$ and 4% per year for the minimum period of 11 years operation. If the life is increased to 17 years, the cost will level off and remain near constant due to economies in final years of operation and elimination of development costs. Using the above yearly increment in costs, the maximum cost per pound of copper is

an estimated 40 cents per pound and the minimum is estimated at 28 cents based on total costs during 1967.

Total production costs within the limits assumed are summarized as:

634,000,000 lbs Cu...@28¢ cost= $178,000,000; @40¢ cost= $254,000,000

820,000,000 lbs Cu...@28¢ cost= $230,000,000; @40¢ cost= $328,000,000

<u>Estimated net profit</u>. Combining the above two tables of indicated gross revenue and costs per pound of copper, estimated profits, within the limits set, may be tabulated as:

lbs Cu produced = 634,000,000
years of production = 11

1.	Gross revenue @ 40¢ per lb -	$ 254,000,000
	Total costs @ 28¢	178,000,000
	Net revenue....	$ 76,000,000
2.	Gross revenue @ 50¢ per lb -	$ 317,000,000
	Total costs @ 28¢	178,000,000
	Net revenue....	$ 139,000,000
3.	Gross revenue @ 50¢ per lb -	$ 317,000,000
	Total costs @ 40¢	254,000,000
	Net revenue....	$ 63,000,000

lbs Cu produced = 820,000,000
years of production = 17

1.	Gross revenue @ 40¢ per lb -	$ 328,000,000
	Total costs @ 28¢	230,000,000
	Net revenue....	$ 98,000,000
2.	Gross revenue @ 50¢ per lb	$ 410,000,000
	Total costs @ 28¢	230,000,000
	Net revenue....	$ 180,000,000
3.	Gross revenue @ 50¢ per lb -	$ 410,000,000
	Total costs @ 40¢	328,000,000
	Net revenue....	$ 82,000,000

Present value. Craigmont's present value is a sum based on current dollar valuation that future earnings from copper concentrate production are worth. The difference between anticipated earnings and present value is the amount of interest that present value could be expected to earn.

Evaluation of Craigmont's present value is based on an annuity at compound interest. This method was used because it does not include risk or capital redemption factors. Risk factors were considered earlier in calculating maximum and minimum net incomes.

Present values determined by the compound interest annuity method are tabulated in Table 16. A uniform annual income is assumed although this would not be true in reality. For comparison, interest rates of 7 and 8% are used because they correspond to current investment returns for other businesses. This rate is higher than the 5 percent return on investment most mining companies have averaged in the past.

Common share value. According to Raymond (1964) a share of common stock is an equity in the mine and if a good fair market value is determined, the total value of the shares should theoretically represent the present value of all future income. This provides the basis for evaluating the intrinsic value of common shares.

The present values per common share are presented in Table 16. Extreme variations in present values of shares depending upon varying factors used in the above calculations are shown. Determining the more

TABLE 16

PRESENT VALUE OF CRAIGMONT'S ESTIMATED FUTURE INCOME*

$$PV = \frac{A\,(R^n - 1)}{R^n\ r}$$

$$PV = A \times \text{Table factor}$$

A = annual income
R = amount of $1 with one year's interest = 1-r
r = rate of interest
n = years active life

Percent compound interest	Number of years	Net income	Annual net income	Table** factor	Present value	PV per share 5,0777,275 shares
7	11	$139,000,000	$12,600,000	7.499	$94,500,000	$18.60
7	11	76,000,000	6,900,000	7.499	51,700,000	10.20
7	11	63,000,000	5,700,000	7.499	42,800,000	8.40
8	11	$139,000,000	$12,600,000	7.139	$90,000,000	$17.70
8	11	76,000,000	6,900,000	7.139	49,200,000	9.70
8	11	63,000,000	5,700,000	7.139	40,700,000	8.00
7	17	$180,000,000	$10,600,000	9.763	$103,500,000	$22.00
7	17	98,000,000	5,800,000	9.763	56,500,000	11.10
7	17	82,000,000	4,800,000	9.763	46,900,000	9.25
8	17	$180,000,000	$10,600,000	9.122	$96,800,000	$19.00
8	17	98,000,000	5,800,000	9.122	33,000,000	10.40
8	17	82,000,000	4,800,000	9.122	43,800,000	8.65

* Present value assuming uniform net income for a minimum of 11 years and a maximum of 17 years at compound interest rates of 7 and 8%.

** The table factor is from valuation Table 4 in Parks (1957).

correct value is difficult. The writer favours the present value of $9.70 per share shown in Table 16 because this value reflects the market price (May 1968) and thus agrees with Raymond's (1964) hypothesis. The PV of $9.70 per share also is based on present reported reserves by the company and assumes a copper price of 40 cents and costs of 28 cents.

History of common shares. When Craigmont stock was first issued in 1951, it was sold over the counter as unlisted stock. Not until some potential was realized for the Merritt property in 1956 were the shares registered with the British Columbia Superintendent of brokers. In March 1958 Craigmont stock was listed on the Vancouver Stock Exchange and in September of the same year on the Toronto Stock Exchange. At present Craigmont has 5,077,275 common shares issued of which Canex hold 2,264,050 (44.6%); Noranda hold 1,000,491 (19.7%); and Peerless holds 870,991 (17%); and the remaining 941,743 are owned publicly (19.7%) (Survey of Mines, 1967).

The activity of Craigmont's common shares since they were first listed in 1958 to the end of 1967 are shown on Figure 14. At the time of initial listing on the Toronto Exchange, the market price per share was near $2.70 and reached a low of $2.10 a month after listing. After this initial dip the market price rose to a high of about $5.25 per share in April 1959. The rapid increase in stock value probably resulted from public awareness as a result of the stock being listed on the exchanges. This period also corresponded to an increase in underground exploration

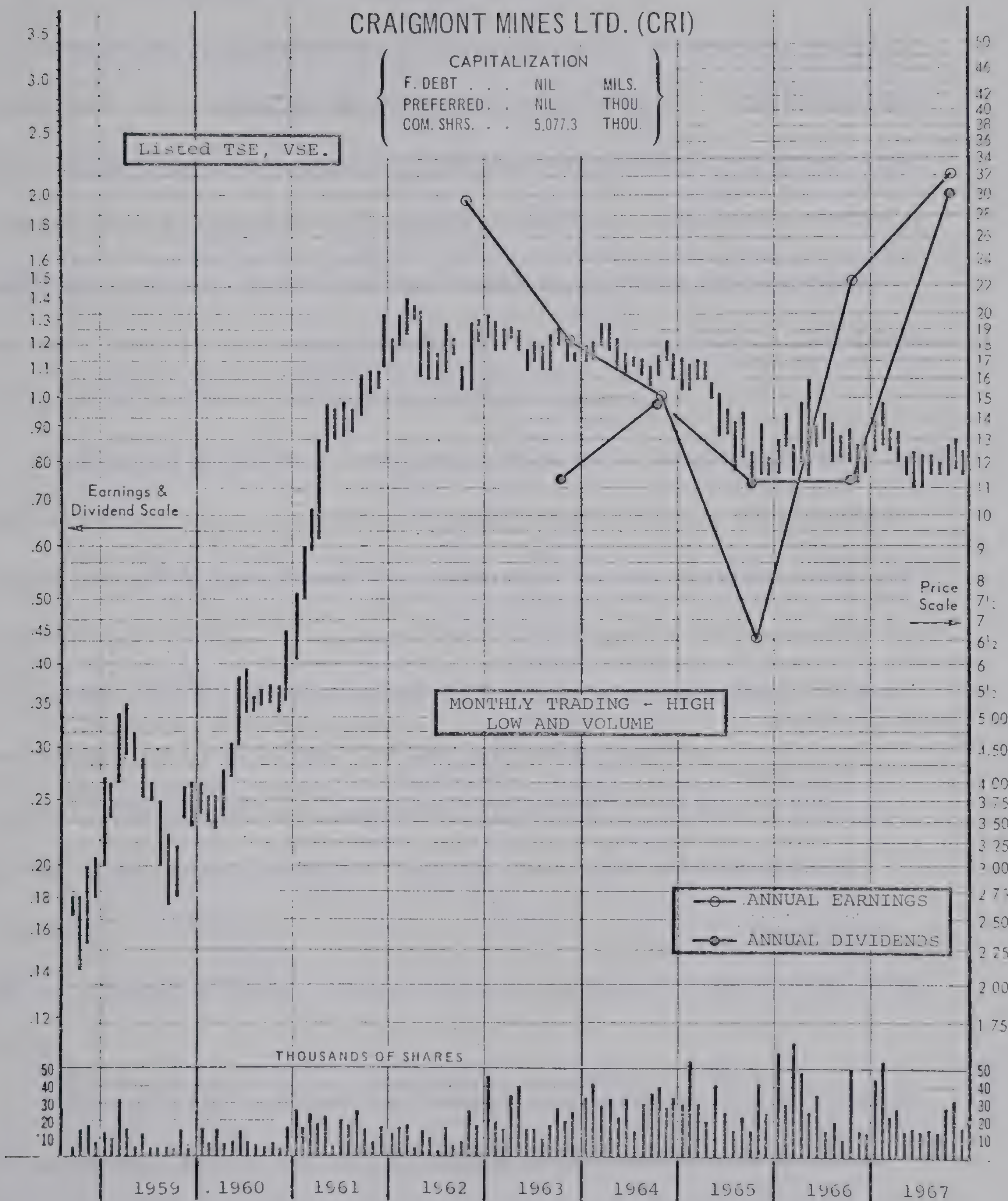


Figure 14. Monthly price range of Craigmont's common shares, volume of shares traded, annual earnings and annual dividends from September 1958 to December 1967.

and the first inkling that production was feasible.

Immediately following the rapid price rise of the shares, the price dipped to a low of about $2.60 before swinging up again in October 1959. A writ served against Craigmont to contest the ownership of a few major mineral claims could have contributed to the dip in stock price. Another possibility was that initial investors began to sell their shares to take profits. However the monthly volume of share trading shown at the bottom of Figure 14 indicates that trading was extremely low.

Beginning in October 1959 Craigmont's stock dramatically increased. Impetus was given to the price increase by the discovery of new underground ore and announcement that production was to commence with low cost open pit mining. At the same time as Craigmont was preparing for production, there was much fervor in British Columbia mining. Many new companies were formed and this attracted numerous investors. Shares of Craigmont stock reached a high of $21.37 in March 1962, six months after production began. In a five month period immediately before production began the price increased from $5.50 to $13.00 per share. Volume of shares traded during this period remained remarkably steady.

Between 1962 and early 1965 the price remained relatively steady averaging near $17.00. At the beginning of 1963 the volume of shares traded increased significantly, but this was not reflected in the price. A downward trend in share price is evident in early 1965, reflecting the declining earnings per share attributal to lower grade of material milled.

This trend is classical in that it illustrates the effect a wasting asset has on its stock price. During the $7\frac{1}{2}$ month-long strike in late 1965 and early 1966, the stock price fell as low as $11.50 with correspondingly high trading volumes, the highest in Craigmont's history. During 1966 profits rose and reached record highs in 1967, but the price of the stock only briefly rose to $16.00 and for the most part averaged about $10.00 per share.

SUMMARY

The chalcopyrite-magnetite-specularite ore bodies at Craigmont are found in Upper Triassic Nicola Group rocks within the southern periphery of the Guichon Creek Batholith. Recrystallized limestone or marble that locally has been altered to skarn is the main host for Craigmont mineralization. Actinolite-rich skarn has the greatest concentration of chalcopyrite and is the most abundant of the skarn rocks. Structural control of the skarn rocks and the orebodies appears to be drag folding on the north limb of an east-west anticline.

Chemical analyses of skarn rocks suggest that Si, Fe, Mg and S were added to the limestones. The metasomatism seems to have taken place under conditions of hornblende - hornfels facies metamorphism. Two distinct stages of metallization occurred at Craigmont. Initially, magnetite, chalcopyrite and specularite formed simultaneously with the skarnification. During the second slightly later phase, veins containing specularite-magnetite, chalcopyrite and K-feldspar formed. The character of the Craigmont deposits places them into the contact metamorphic class of ore deposits.

According to available radiometric data (Tozer, 1964), the 198 m.y. age of the Craigmont mineralization assigns emplacement of the deposit to the Upper Triassic Norian stage.

White and Carter (1968) believe that during late Triassic and early Jurassic, a fairly extensive metallogenic epoch occurred in British

Columbia. Mineral deposits known to have formed during this epoch based on K-Ar dating are: Bethlehem, Copper Mountain, Stikine Copper and now Craigmont. At each mineral property, related intrusive rocks, radiometrically the same age as the mineralization, indicate a genetic association between plutonism and mineralization. At Craigmont sulfur isotopes suggest that sulfides in the batholith and orebodies may be related. Most sulfur data indicate a deep-seated source for sulfur in the sulfide minerals. This hypothesis is substantiated by the initial Sr^{87}/Sr^{86} ratio from K-feldspar gangue and from low carbon isotope values for calcite associated with the ore.

The principal host rocks (other than granitic rocks) for copper deposits in British Columbia are Upper Triassic and Jurassic volcanic rocks. These rocks are notably rich in trace amounts of copper (100 ppm) according to White (1966). These factors have led many workers (Ney, 1966) to suggest that these rocks may have been a major copper source. Volcanic rocks in the Nicola Group are not abundant at Craigmont, but interestingly the sulfur isotopes suggest that some of the sulfur is from the country rocks.

Craigmont's short seven year history from discovery to production shows the successful result of modern exploration techniques conducted by experienced personnel. By using a carefully planned program, the staff efficiently outlined the orebodies and determined the most suitable mining and milling plans. Craigmont's approach should serve as a model to other prospecting companies and mines contemplating production.

Preproduction expenditures amounted to nearly 18 million dollars. Craigmont's success is illustrated by the fact that during its first three years of production the approximately 15 million dollars obtained from issued preferred shares and banks was completely repaid. The borrowed capital was utilized for construction of mill-surface buildings and mine-mill equipment purchases. Craigmont has successfully used the most modern mining methods and equipment available since it began production in 1961.

Open pit mining was terminated in March 1967 after the pit reached its ultimate depth. A sub-level cave mining method is currently being developed to recover the remaining underground ore. Sub-level mining at Craigmont is feasible due to introduction of highly mechanized long-hole drilling equipment, trackless extraction units and improved blasting techniques. The cost of using this method will greatly influence Craigmont's future profits.

Craigmont's life and profits are intimately related to future copper prices, world copper markets and production costs. If the current production rates are maintained, Craigmont's remaining life is estimated at 11 years considering reported ore reserves for 1967. An additional 10 million tons of ore will increase the life to about 17 years. If the growth rate of copper consumption averages about 4 to 5% in the future, then possibly Craigmont is assured of average prices and a strong market for sales during its remaining life. The present market price of the common shares appears to adequately reflect the present value of Craigmont's future income.

PLATE I

PHOTOMICROGRAPHS OF THIN SECTIONS

Figure

1. Recrystallized limestone with mosaic texture of lamellar twinned calcite crystals. Minor amounts of quartz (white) and chlorite (dark grey) are present. From underground near main orezone. (#6255, plain light, 25X)

2. Foliated marble with elongation of lamellar twinned calcite crystals. Collected 100 feet from known mineralization underground. (#6272, X-nicols, 62X)

3. Polycrystalline quartz porphyroblast in a groundmass comprised of fine-grained quartz, feldspar, chlorite, epidote and magnetite. From a hornfelsed wacke in open pit. (#6251, X-nicols, 25X)

4. Sericitized feldspar porphyroblast in fine-grained cherty groundmass. From a hornfelsed argillite outcropping in open pit. (#6248, X-nicols, 62X)

5. Interstitial late calcite (twinned) surrounded by strong perthite. Narrow strings of albite have exsolved from potassium feldspar. From a veinlet in open pit rich in K-feldspar gangue. Specimen was used for Rb-Sr dating. (#6243, X-nicols, 25X)

6. Potassium feldspar (light grey) replacing epidote (dark grey). Chlorite (medium grey) has formed interstitially. Considerable iron stain developed on feldspar crystals. From a hornfelsed quartzofeldspathic sandstone from underground. (#6262, plain light, 62X)

7. Large aggregates of chlorite crystals and secondary interstitial chlorite partly replacing quartz. The chlorite which has brown interference colour is magnesium rich. From chlorite skarn underground. (#6258, plain light, 25X)

8. Same as preceding Fig. except nicols are crossed and show characteristic bow-tie texture. From chlorite skarn underground. (#6258, X-nicols, 25X)

PLATE I

PLATE II

PHOTOMICROGRAPHS OF THIN SECTIONS

Figure

1. Graphic intergrowth of potassium feldspar (black) and quartz. From a 2 foot thick vein from underground rich in K-feldspar gangue. Specimen used for Rb-Sr dating. (#6259, X-nicols, 40X)

2. Altered crystal of basaltic hornblende with biotite core. Note reaction rim around crystal. Matrix is comprised of plagioclase microlites. From hornblende basalt of Kingsvale Group outcropping at top of open pit south wall. (#6253, X-nicols, 62X)

3. Twinned and zoned plagioclase crystal, the light coloured area represents newly formed lamellae, and the dark areas interspaces. Zoning is preserved only in the interspaces. Sericite developed along some zones. Euhedral hornblende (black) and plagioclase laths comprise remainder of specimen. (#6253, X-nicols, 40X)

4. Plagioclase microlites have a trachitic texture around highly altered basaltic hornblende. Cloudy crystals are plagioclase phenocrysts. From Kingsvale andesite at top of south-wall open pit. (#6252, plain light, 62X)

5. Calcite veinlet cutting groundmass of euhedral specularite (black), quartz (white) and chlorite-actinolite (grey). Note pitted rims on the quartz crystals. From actinolite epidote chlorite skarn, underground. (#6256, plain light, 62X)

6. Interstitial chalcopyrite (black) associated with twinned calcite and quartz (grey) crystals which are at different stages of extinction. Quartz contains inclusions of magnetite dust and apatite. (#6256, X-nicols, 62X)

7. Euhedral quartz crystal grown in calcite. Chalcopyrite (black) has developed in one end of the crystal. From main orezone underground. (#6264, X-nicols, 25X)

8. Massive magnetite including some euhedral grains developed in potassium feldspar (light grey). Minor amount of chlorite (dark grey) also present. From east end of main orebody underground. (#6271, plain light, 100X)

PLATE II

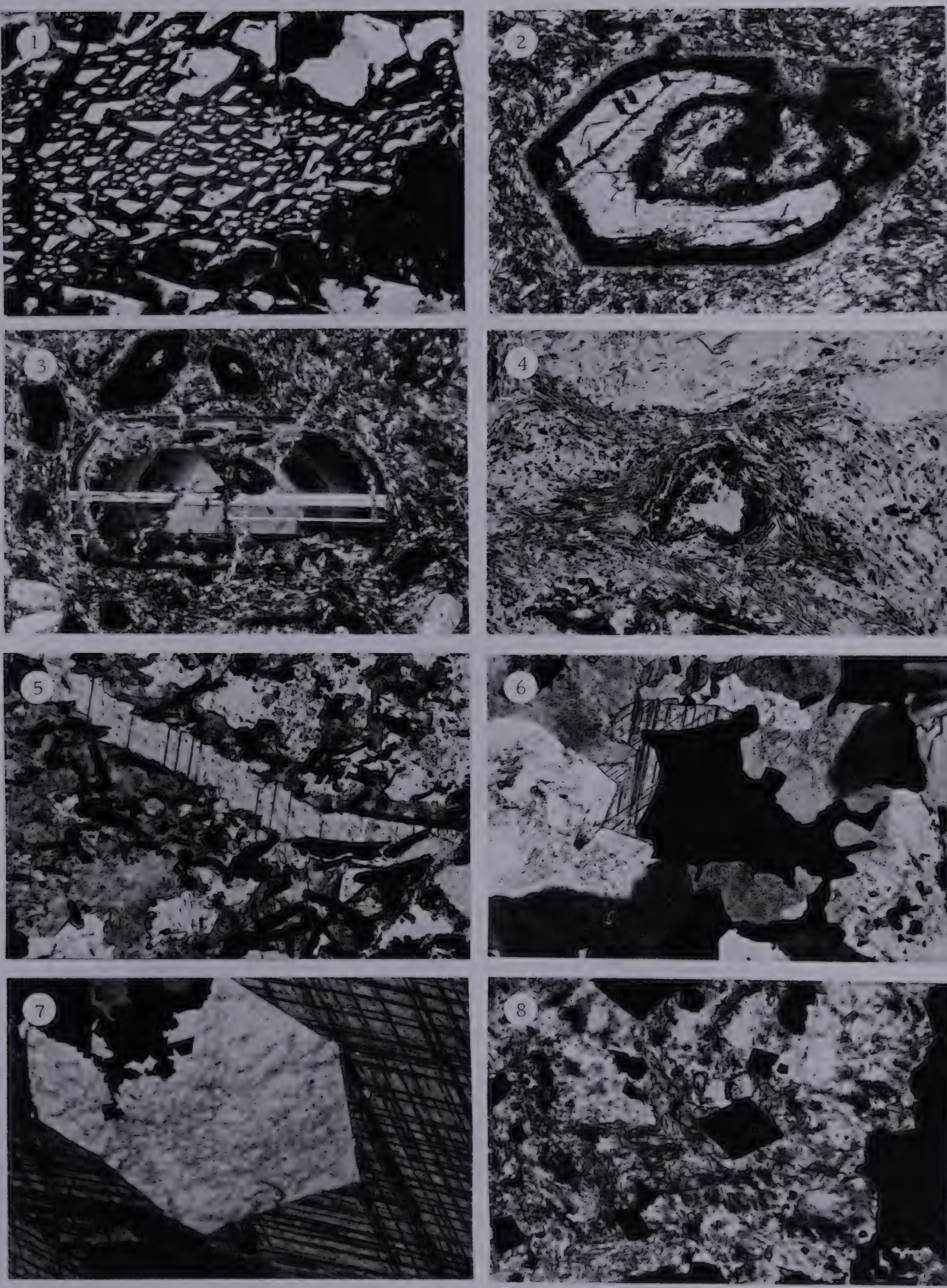


PLATE III

PHOTOMICROGRAPHS OF POLISHED SECTIONS

Figure

1. Fractured platy magnetite cut by veinlets of quartz (black) and chalcopyrite (white). Deposition of these minerals was partially controlled by the magnetite crystal boundaries. From east end of orebody underground. (#6271, plain light, 62X)

2. Euhedral magnetite crystals in quartz gangue. Same specimen as preceding Figure. (#6271, X-nicols, 100X)

3. Rumpled specularite laths and euhedral crystals of ilmenite (hexagonal) are the two metallic minerals present. Dark gangue minerals are K-feldspar and chlorite. From veinlet associated with K-feldspar gangue at west end of open pit. (#6250, plain light, 260X)

4. Specularite crystals containing interstitial silicates (black) show overlapping form. A minor bleb of chalcopyrite occurs between specularite laths in lower right corner. Same specimen as preceding Figure. (#6250, plain light, 160X)

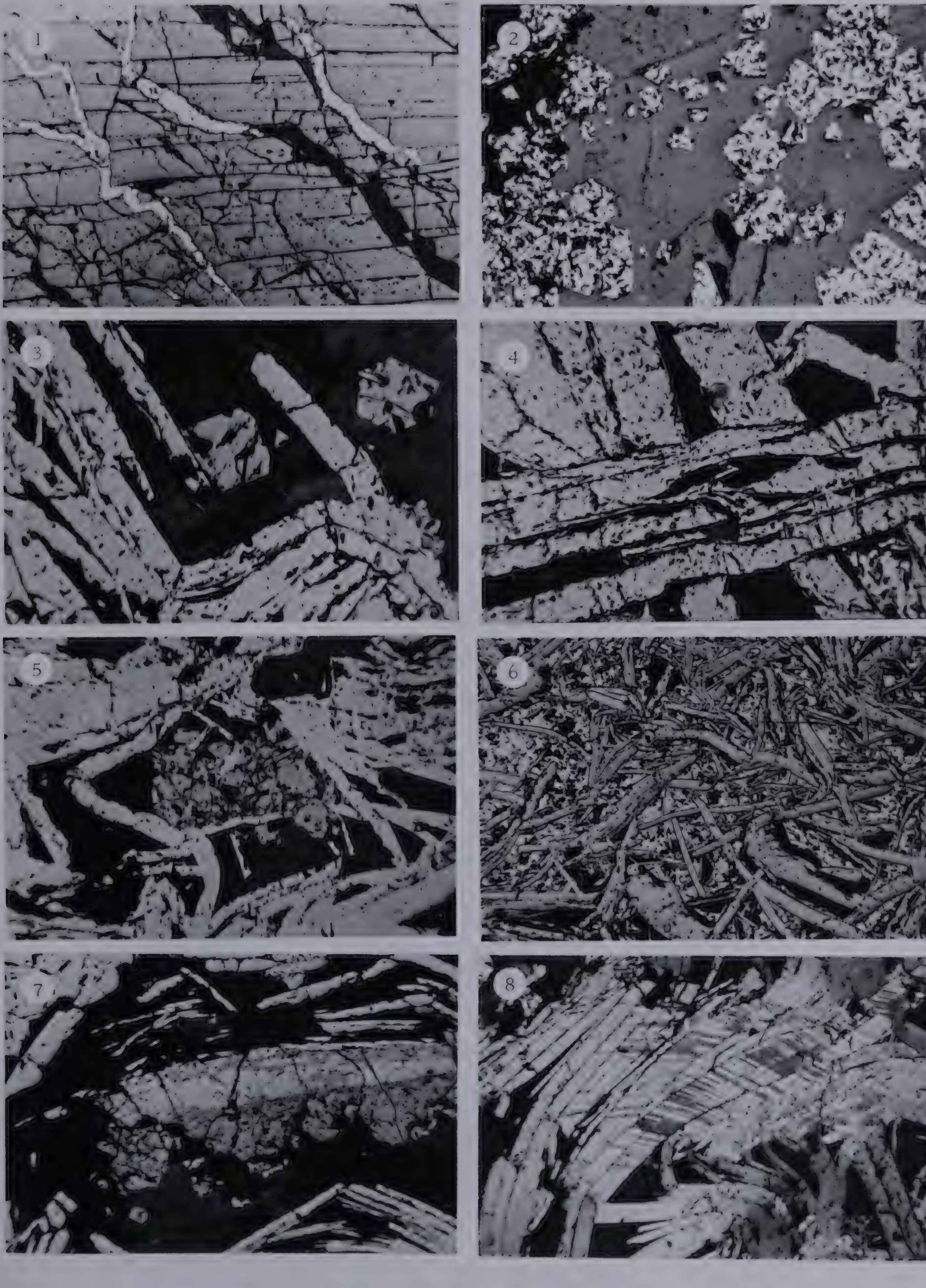
5. Fractured bornite crystal (dark grey, center) is associated with specularite (light grey), quartz, and chlorite. From massive specularite zone in northwest corner of open pit. (#6249, plain light, 500X)

6. Rumpled specularite is interspersed in chalcopyrite (light grey) and silicate gangue. Same specimen as preceding Figure. (#6249, plain light, 62X)

7. Magnetite (dark grey) has partially replaced specularite crystal (light grey). Black areas are gangue minerals. From main orebody underground. (#6261, plain light, 62X)

8. Bent specularite crystals illustrating partially rotated lamellar twinning. Black areas are gangue minerals. (#6250, X-nicols, 62X)

PLATE III



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APPENDIX A

Specimens from Craigmont Mine, B. C.

Note: Number in ( ) refers to those labelled on specimens. Mine coordinates are used.

M6243	(C-1)	Feldspathic gangue, 10300N, 9370E, 3600 elev.
6244	(C-2)	Chlorite, epidote, garnet skarn; 10330N, 9410E, 3666 elev.
6245	(C-3)	Massive magnetite, 10330N, 9400E, 3666 elev.
6246	(C-4)	Diorite, 10315N, 9570E, 3666 elev.
6247	(C-5)	Andesite hornfels, 9985N, 8560E, 3534 elev.
6248	(C-6)	Argillite hornfels, 10010N, 8400E, 3564 elev.
6249	(C-7)	Skarn with specularite and chalcopyrite, 10150N, 8370E, 3534 elev.
6250	(C-8)	Feldspathic gangue, 10140N, 8320E, 3534 elev.
6251	(C-9)	Chlorite hornfels, 10210N, 8480E, 3468 elev.
6252	(C-10)	Andesite (Kingsvale Group), 9480N, 8130E, 4062 elev.
6253	(C-11)	Hornblende basalt (Kingsvale Group), 9480N, 8130E, 4062 elev.
6254	(C-12)	Diorite, 3060 elev. at shaft #2.
6255	(C-13)	Marble with minor skarn minerals, 3060 elev. at shaft #2.
6256	(C-14)	Actinolite, epidote, chlorite skarn, 30-783 Service drift east.
6257	(C-15)	Massive specularite, 30-783 Service drift east.
6258	(C-16)	Chalcopyrite and skarn minerals, 30-783 Service drift east.
6259	(C-17)	Feldspathic gangue, 3590 elev. at 771 Ore pass.
6260	(C-18)	Diorite? highly altered, 3590 elev. at foot of 3620 ramp.
6261	(C-19)	Massive magnetite and specularite, 3464 elev. in Haulage drift #1.

6262	(C-20)	Hornfelsed quartzofeldspathic sandstone; 3465-3537 Ramp, south of Shaft #1.
6263	(C-21)	Hornfels wacke, 34-751 Access drift.
6264	(C-22)	Chalcopyrite, quartz skarn and calcite, 2852 elev. 821 Crosscut north.
6265	(C-23)	Magnetite skarn, 2852 elev. 821 Crosscut north.
6266	(C-24)	Hornblende diorite, 2852 elev. at shaft #2.
6267	(C-25)	Hornblende diorite, 2852 elev. at shaft #2.
6268	(C-26)	Andesite; On Spences Bridge road 7/10 of a mile west of the Craigmont road turnoff.
6269	(C-27)	Volcanic breccia from Diamond drill hole #S-61.
6270	(C-28)	Porphyritic andesite; from Craigmont surface diamond drilling.
6271	(C-29)	Massive magnetite with K-spar; from 3500 elev. Specimen was collected by Rennie in 1961 and a K-Ar age determination was made on it . (AK-209).
6272	(C-30)	Pure marble, 10530N, 7400E, 3070 elev.
6273	(C-31)	Marble with some skarn minerals, 10390N, 7470E, 3065 elev.

6274	(C-32)	Powdered limestone taken from outside the brachial valve of a Linoproductus cora (d'Orb) Permian from the fossil collection of P. S. Warren at the Univ. of Alberta.
6275	(C-33)	10625N, 7385E, 3533 elev. Recrystallized limestone
6276	(C-34)	Limestone, 10080N, 7550E, 3560 elev.
6277	(C-35)	Calcite veinlet, 10175N, 8720E, 3390 elev.
6279	(C-37)	Impure black limestone, 9300N, 700E, 5165 elev.

6280	(C-38)	Recrystallized limestone, 7500N, 2400E, 5265 elev.
6281	(C-39)	Limestone skarn, 10970N,2540E, 4550 elev.
6282	(C-40)	Young calcite veinlet hydrothermal, 11520N, 2440E, 2630 elev.
6283	(C-41)	Partly recrystallized limestone, 9200N, 210E, 4525 elev.
6284	(C-42)	Limestone skarn, 10168N, 6865E, 3068 elev.
6285	(C-43)	Limestone skarn, 10224N, 6857E, 3070 elev.
6286	(C-44)	Limestone breccia cemented with a remobilized calcite, 10264N, 6851E, 3072 elev.
6287	(C-45)	Limestone skarn, 10317N, 6843E, 3074 elev.
6288	(C-46)	Limestone skarn, 10215N, 7460E, 3015 elev.
6289	(C-47)	Limestone skarn, 10270N, 7452E, 2985 elev
6290	(C-48)	Limestone skarn, 10300N, 7447E, 2965 elev.
6291	(C-49)	Limestone skarn, 10325N, 7444E, 2950 elev.
6292	(C-50)	Relatively unaltered limestone, 10355N, 7440E, 2935 elev.
6293	(C-51)	Limestone skarn, 10105N, 7478E, 3082 elev.
6294	(C-52)	Relatively unaltered limestone, 9785N, 7535E, 3347 elev.
6295	(C-53)	Calcite veinlet, 10515N, 7406E, 3674 elev.

APPENDIX B

RB-SR ISOTOPES

Sample preparations:

In order to determine samples that would be most practical for Rb-Sr or K-Ar dating, all specimens collected at Craigmont were analyzed for their Sr, Rb, and K_2O contents by X-ray fluorescence analysis. From these results six samples with the highest Rb to Sr ratios were selected for Rb-Sr dating. No samples warranted K-Ar dating.

Rubidium separation:

Sufficient sample to give a $^{87}Rb/^{85}Rb$ ratio of approximately two (including the spike) was weighed into a platinum dish and moistened with water. Five drops of sulfuric acid (H_2SO_4), five milliliters (ml) of hydrofluoric acid (HF) and a precalibrated ^{87}Rb enriched spike was added. The sample was decomposed by heating on a hot plate and evaporated to dryness. The residue was fumed at 500-600° C. and then ignited for 30 minutes at a temperature of 900° C. After cooling, the residue was warmed gently and leached with about 2 ml of demineralized water. The leachate was transferred to a small glass vial, evaporated to dryness and stored for mass spectrometer analysis.

Strontium separation:

A sample containing sufficient strontium to give about 15-20

micrograms of total strontium (enough for spiked and unspiked aliquots) was weighed into a teflon beaker. The sample was moistened with demineralized water and 10 ml of HF acid, 10 ml of redistilled 1: 1 nitric acid (HNO_3) were added. The solution was evaporated to dryness at about 120^o under protective polypropylene hood. The residue was moistened with demineralized water and 5 ml of 1:1 HNO_3 and evaporated to dryness after which it was baked for two hours. To the baked residue 8-10 drops of perchloric acid were added and fumed-off slowly. To disolve the residue 10 ml of 2.5 normal HCl was added followed by about 100 ml of demineralized water. From this solution an aliquot was weighed out and a strontium tracer or spike was added. The spiked and unspiked solutions were then centrifuged to settle out any insoluble material. The soluble solutions were then passed through calibrated ion exchange columns where the strontium fraction was collected. After heating to dryness, the residue was ready for mass spectrometer analysis.

Isotope measurements:

A six inch, 60 degree deflection solid source mass spectrometer with a single filament source and a single collector cup was used to measure the rubidium and strontium isotope ratios. All the Rb and Sr runs were recorded on a chart recorder and in conjunction with a digital voltmeter. The detailed mass spectrometer procedures used by the Department of Geology, University of Alberta and for this study have been recently summarized by De la Cruz (1967).

Calculation of results:

An APL computer program, "RBSRISOCHRON," was written by Dr. H. Baadsgaard (based on the work of York, 1966) to calculate the Rb-Sr mass spectrometer measurements. The corrected data from the digital voltmeter is typed directly to the computer. The program uses a double regression analysis to draw a line of best fit through the experimental data. The output gives the slope and initial ratio with estimates of the uncertainties, the value of mean square deviates, the center of gravity of the data and the age within 68% confidence limits.

APPENDIX C

SULFUR ISOTOPES

Sample preparation:

Sulfide minerals were separated from gangue by hand picking except for a few samples with finely disseminated pyrite which were separated by heavy liquids. Two batholith samples with trace amounts of sulfides were chemically leached to concentrate the sulfur as sulfate first, then converted to silver sulfide using the method described by Thode et al., (1961). All sulfides were converted to sulfur dioxide gas for ease of mass spectrometer measurement by burning the sulfide mineral in pure oxygen with a constant isotopic composition at 1200^0C. A series of cold traps were used to freeze the SO_2 from other contaminants such as oxygen, carbon dioxide and water. The SO_2 was finally trapped into a glass breakseal for mass spectrometer analysis.

Isotope measurement:

A 12 inch, 90 degree magnetic analyzer mass spectrometer that was equipped for simultaneous collection of masses 66 and 64 was used to measure sulfur isotope raios. In this machine, a digital voltmeter and recorder combined with a voltage-to-frequency converter made it possible to print directly the (Mass) 66/(Mass) 64 ratio for the sample (McCullough and Krouse, 1965). During analysis, the isotope ratios in each sample were compared with the ratio in a secondary laboratory standard which was collated with the troilite sulfur of the Cañon Diablo

meteorite. The detailed mass spectrometer procedures used for this study have been summarized in detail by Ryznar (1965).

The calculated analytical precision of the present study based on reproducibility expressed as standard deviation was $\pm$ 0.2 permil of the S^{34}/S^{32} ratio.

APPENDIX D

OXYGEN AND CARBON ISOTOPES

Sample preparation:

Coarse calcite crystals and whole rock carbonate samples were first analyzed by X-ray diffraction to determine if dolomite was present. Representative thin sections were also strained with Alizarin Red-S to help distinguish calcite from dolomite. In all samples the dolomite content was negligible. Each sample was converted to carbon dioxide gas for mass spectrometer measurement by reacting with phosphoric acid at 25^{o}C in a vessel connected to an extraction train. This system consisted of a vacuum and a series of cold traps that separated the CO_2 from other contaminant gases and water by freezing. The CO_2 was eventually frozen in a breakseal for mass spectrometer analysis. The detailed sample preparation, CO_2 collection methods and mass spectrometer procedures used for this study have been summarized in detail by Singh (1967).

Isotope measurement:

The same mass spectrometer used for sulfur isotopes was used for carbon and oxygen isotope measurements with a different collector system. The mass spectrometer has a 12 inch, 90 degree magnetic analyzer and is equipped with a double collector for carbon and oxygen analysis. During measurement, the carbon or oxygen ratios of each sample were compared with the ratios from a secondary standard CO_2

that had approximately similar isotopic composition to the analyzed samples. The results were then equated to the PDB standard. All analyses were recorded on an integrating digital voltmeter recorder and on a chart recorder. Measured values were corrected for tail effects and for the effect of variation in O^{17} on δC^{13} and in C^{13} on δO^{18} (Craig, 1957).

The reproducibility of the mass spectrometer analysis was better than $\pm$ 0.1 permil and the overall reproducibility better than $\pm$ 0.2 permil.